R. B. Lindsay

70–1

Proceedings of the American Academy of Arts and Sciences.

Vol. 70. No. 1.—March, 1935.

THE MELTING CURVES AND COMPRESSIBILITIES OF NITROGEN AND ARGON.

By P. W. Bridgman.

Investigations on Light and Heat made and published with aid from the Rumford Fund.

(Continued from page 3 of cover.)

VOLUME 70.

1. Bridgman, P. W.—The Melting Curves and Compressibilities of Nitrogen and Argon. pp. 1–32. March, 1935. $0.65.

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Received October 1, 1934. Presented October 10, 1934.

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INTRODUCTION.

DURING the last few years a revival of interest in the question of the possible existence of a critical point between solid and amorphous phases has been inspired by new measurements on several of the permanent gases, a particularly simple class of substance. These measurements are due primarily to Simon and his collaborators,[1] who have followed the melting curve of helium to approximately 5500 kg/cm^2, that of hydrogen to 5000, that of neon to 4900, that of nitrogen to 5000, and that of argon to 3400. However, there are also a number of measurements from the laboratory at Leiden,[2] over a much smaller pressure range, but with greater precision. It is the opinion of Simon that the melting curve will end in a critical point, but in no case has such a critical point actually been realized. In the failure actually to realize the critical point the course of the melting curve itself can give no basis for an extrapolation, which can be made only with the help of other independent data. Thermodynamically, the critical point is characterized by the simultaneous vanishing of the difference of volume between the two phases and of the latent heat of the transition. If a critical point is to be justifiably inferred from extrapolation from data in the experimental region, then the course of the curves for difference of volume and latent heat in the experimental range must be such as to indicate the vanishing of the volume difference and the latent heat within distances not too remote from the region of experiment, and furthermore, the extrapolated vanishing pressure (or temperature) for volume change must be the same as the extrapolated vanishing pressure (or temperature) for latent heat. Simon did not make measurements of either change of volume or of latent heat, so that up to the present there is no basis for extrapolation, and no possibility of setting up a rigorous argument for a critical point, from the new data for the permanent gases.

In this paper I present new measurements of the coordinates (pressure and temperature) of the melting curves of argon and nitrogen up to about 5500 kg/cm^2, and also measurements of the difference of volume. As is well known, the latent heat of the transition may be computed from the volume difference and the coordinates of the melting curve by means of Clapeyron's equation, so that we now have the means of making an extrapolation toward a possible critical point for these two gases. Furthermore, in the course of the measurements of the volume difference it was necessary to know the volumes of the gaseous phase; these apparently have not been previously determined at temperatures below 0° C at pressures higher than 200 or 300 kg, so that it was necessary to determine a number of points on the p-v-t surface of the gas in the new region. These determinations, which have an interest in themselves apart from the problem of change of phase, are also given in the following.

APPARATUS.

The large features of the apparatus were determined by the general method, which was the same as that employed in my previous work on change of phase of substances liquid under ordinary conditions.[3] Pressure was produced by the motion of a leak-proof piston. Change of phase is accompanied by a discontinuity in the motion of the piston as a function of pressure. The pressure of the discontinuity at a given temperature gives the p-t coordinate of a point on the melting curve, and the amount of discontinuity gives the volume change. These new measurements differ from the previous ones in that gases are being dealt with instead of liquids, and by the low temperatures, running down to 77° K, so that appropriate changes in the apparatus were necessary.

The apparatus already employed for the measurement of electrical resistance as a function of pressure at low temperatures[4] could be adapted to the demands of this method with very few changes. The apparatus consists essentially of a couple of precompressors, by which the gas is raised from the tank pressure of approximately 100 kg/cm^2 to 2000 kg/cm^2, an upper cylinder maintained at room temperature, in which pressure is produced by the motion of a leak-proof piston, and in which is installed the manganin gauge by which pressure is measured, a connecting pipe, and the lower cylinder, maintained at the desired temperature by a low temperature thermostat to be described later, in which the freezing of the gas takes place. The diameter of the hole in the upper cylinder was about 0.67 cm, and its length 8.6 cm, making a total capacity in the upper cylinder of about 2.8 cm^3. The lower cylinder was also 0.67 cm in internal diameter, with a total capacity of about 3.8 cm^3. The connecting pipe was 30 cm long, with a total internal volume of 0.13 cm^2, and an outside diameter of 0.48 cm. The upper cylinder carries only one side hole, that for the manganin gauge, instead of the four holes which were necessary in the previous experiment; this results in a very desirable simplification of construction and assembly. The screw plug by which the manganin gauge is retained against pressure is carried in a heavy ring, girdling the cylinder, and a push fit for it, as in the previous experiments.

In my previous measurements of change of phase under pressure, the substance undergoing transition was usually separated from the pressure transmitting liquid, which was some light hydrocarbon, by mercury. This is now obviously impossible; furthermore, there seems to be no method of separating one fluid from another without mixing in the range of pressures and temperatures involved, so that the entire apparatus had to be filled with the substance whose transition was being measured. This necessity gave rise to considerable misgiving, for I had already tried without success to measure the compressibility of some of the permanent gases by the piston displacement method. The difficulty was the penetration of the steel by the gas, having the same effect, as far as measurements of volume in terms of piston displacement are concerned, as a leak. It was the same penetration of the steel by the helium which set the maximum limit of 7500 kg/cm^2 reached in my previous experiments on resistance at low temperatures. However, previous experiments had shown that penetration by nitrogen is usually not nearly so serious as penetration by helium, and on one occasion I had reached a maximum pressure of 12000 kg/cm^2 with nitrogen, although this could not be permanently retained, so that the problem did not appear hopeless if one were willing to restrict oneself to comparatively low pressures. It appeared, moreover, that Simon had been having no such difficulty as I from the penetration of his steel. I therefore obtained, through the kind offices of Dr. Simon, for which I am very much indebted to him, from the German firm Bismarckhütte, Berlin, some of the same steel which he had been using. A test cylinder made from this withstood without rupture a maximum pressure of 12000 kg/cm^2 exerted by helium, although the pressure was not permanently retained, but slowly dropped, thus showing some absorption by the steel. The performance was very much better than that of any steel which I had previously tried, however, and the entire apparatus was therefore constructed from this German steel. It is a chrome-nickel steel, the exact composition of which I do not know, but it is obviously low in carbon. It is supplied in a heat treated condition, soft enough for ordinary machining operations, with a tensile strength of about 150,000 lb/in^2. The upper and lower cylinders were machined from the steel as supplied. The steel was too hard, however, to permit drilling the hole 30 cm long and 0.08 cm in diameter for the connecting pipe, so that the steel from which the pipe was made was first annealed and then reheat-treated after fabrication.

The apparatus constructed from this steel was used in obtaining the results described in the following up to a maximum pressure of about 6000 kg/cm^2 with no sign at all of penetration either by nitrogen or argon. One connecting pipe split during use, but the original upper and lower cylinder were used throughout. I have not yet had enough experience in handling gases at high pressures to know whether the superior performance of this steel is due to its chemical composition, or to its superior homogeneity and freedom from various sorts of imperfections. This sort of steel is, of course, made in this country also, but I have not yet tried any of American manufacture. One or two metallurgists have suggested that the German steel may be intrinsically superior for this sort of service because it is much freer from impurities of sulfur and phosphorus, the original Swedish ore from which German steels are made being known to be freer from sulfur and phosphorus than any American ores. Sulfur and phosphorus are said to be the most likely constituent of impurities which tend to segregate mechanically in the ingot, which one would expect to result in gas penetrability. If it should turn out that the employment of a CrNi steel, like that used here, is necessary in high pressure gas work, the pressures attainable with gases in experiments of this character would be definitely limited to about 12000 kg/cm^2, the stretch beyond this point in a steel not capable of being heat treated to higher figures becoming too great to permit accurate measurements of volume by the piston displacement method. However, up to pressures of this order it would seem that it is now possible to explore the *p-v-t* surface of gases by a technique distinctly simpler than that used in my previous work. It appears, furthermore, that there are several new possibilities which I have not yet explored in the way of homogenizing steels during the process of manufacture, so that it is not at all impossible that pressures still higher than this will presently be available for experiments of this character on gases.

The motion of the piston which gives the change of volume was measured in two different ways. The first method was that already employed in measuring the compressibility of gases. The hardened plunger is pierced with a small axial hole, through which passes a wire made an integral part of the head of the moving packing plug. The position of the upper end of this wire is read through a suitable peephole milled in the piston of the hydraulic press with a reading telescope and a scale attached to the upper cylinder. In this way the actual motion of the moving plug in contact with the gas is measured, and errors from compression or wear of the packing are eliminated. The second method measures the motion of the piston of the hydraulic press with respect to the upper cylinder by means of two Ames dial gauges of one inch stroke, graduated to 0.0005 inch and easily read to 0.0001, mounted on opposite sides of the press. Calibrated extension rods were provided by which the range could be extended as required beyond the one inch capacity of the gauges. This scheme is much like that used by Adams at the Geophysical Laboratory in his measurements of various compressibilities by the piston displacement method, except that two gauges are used instead of one, thus making possible the more complete elimination of the effects of distortion in the press. The two gauges usually agreed to about 0.002 inch over the entire stroke. The gauges were calibrated over their entire stroke with gauge blocks, and the maximum error found was 0.0005 inch, although the error in a couple of gauges which were discarded was more than this. The mean of the readings of the two gauges should be free from the effects of distortion or other error within about the sensitiveness of the readings. The second method is very much more convenient than the other because the Ames dials are much easier to read than the telescope. After one or two runs had disclosed no perceptible difference between the piston displacements given by the two methods, showing no perceptible wear in the packing, the Ames gauges only were used after the initial measurement, when the telescope and scale also was used in order to give the absolute position of the plunger and so a fiducial point from which could be calculated the absolute volumes which enter into some of the coreections. It proved on working up the results, however, that variations in the initial volumes affect the corrections only within wide limits, so that the information given by the absolute position of the piston did not prove to be important.

The upper cylinder was not provided with a thermostat, but was at room temperature. A small oil bath was built around the cylinder above the ring carrying the screw plug of the manganin gauge, and the temperature was read a number of times during a run with a thermometer immersed in this oil bath. The variation of temperature during a run was seldom more than a few tenths of a degree, and the corrections for this small variation were so easy to apply that the complication of a thermostat was not justified.

The manganin gauge was the identical one which had been used in the previous work on resistance at low temperature; it was wound from wire 0.003 inch in diameter, obtained from Driver Harris. It was however, now subjected to a fresh seasoning procedure, the zero drift having become, in the two years since previously used, somewhat larger than desirable. The seasoning consisted in maintaining it continuously at a temperature of 135° C for three days, except for two excursions for five minutes each to the temperature of solid CO_2. The resistance was lowered 0.45% by the seasoning, and the pressure coefficient dropped 1.79%. The pressure calibration was made in the usual way in terms of the freezing pressure of mercury at 0° C. The drift of the zero was very much reduced by the new method of seasoning; the change of zero in three months time now amounting to an increase of 0.005% of the total resistance. Because of the necessity of getting closely spaced pressure readings in the neighborhood of the transition points, the sensitiveness of the pressure readings was increased nearly five times beyond that of the previous work by increasing the size of the slide wire of the bridge. With the new arrangements, 1000 kg/cm^2 corresponds to a slider displacement of about 24 cm, and it was possible to get readings consistent to 0.1 mm, or about a quarter of an atmosphere, over the entire pressure range. The absolute accuracy of the calibration, of course, does not correspond to this sensitiveness, but small differential effects could be obtained corresponding to this sensitiveness.

The lower cylinder, in which freezing takes place, has to be maintained at constant temperature at any desired point in the range from 77° K to 185° K, and this demanded the construction of a special thermostat. In the previous work only the temperature of boiling oxygen was used, so that formerly the problem was very simple. Boiling oxygen was also used as one of the fixed temperatures in this work, and to this was added boiling nitrogen. The liquid nitrogen was obtained by passing nitrogen from a tank of commercial nitrogen, "99.7% pure," through a copper coil immersed in liquid air, there being a throttle valve on the outlet end so as to maintain a pressure of at least five atmospheres in the gaseous nitrogen and thus permit its liquefaction at the temperature of liquid air. Corrections were made for the barometer when using either of these boiling baths, as had also been done in the previous work.

Above the temperature of boiling oxygen there are no available substances boiling within the range desired, and some sort of stirred and thermostated bath seemed the only possibility in view of the necessity of raising and lowering the cylinder into the bath in order to control the freezing, as will be explained later. The problem of a stirred bath in this range of temperature is one which has been encountered by many other experimenters and has never proved easy of solution. The conditions were in this case perhaps more exacting than usual because of the unavoidably large heat leak into the bath along the connecting pipe. I made a number of attempts before finding the solution adapted to the needs of this particular experiment. The bath liquid finally used was liquid propane, obtained by passing the gas, sold commercially under various trade names in compressed cylinders for domestic use in places where there is no municipal gas supply, through a copper coil immersed in CO_2 and alcohol. The liquefied propane is contained in a thin German silver can of about one half liter capacity, surrounded for heat insulation by a special thermos flask pierced with a hole through the bottom. The propane is stirred by a small turbine stirrer of conventional design. Passing through the propane bath are several turns of light walled copper tubing, connected at the upper end with a source of vacuum, and at the bottom end, through the bottom of the pierced thermos flask, with a source of liquid air. When the temperature rises too high, liquid air is automatically sucked up into the copper tubes, lowering the temperature of the surrounding bath, until the vacuum is again cut off. The temperature regulating member is essentially a hydrogen pressure thermometer. A thin walled copper bulb, of about 8 cm^3 capacity, connects through hypodermic steel tubing of 0.02 cm diameter with a mercury column provided with suitable contacts. The bulb also connects, through suitable reducing valves, with a tank of commercial hydrogen. The height of the mercury column is so chosen that the hydrogen in the bulb is under a pressure of about two atmospheres, thus increasing the sensitiveness. The contacts are made through a vacuum tube arrangement through a thyratron, so that the motor which runs the vacuum pump can be turned on and off with no sparking at the contacts; the sensitiveness is so great that the contact makes or breaks with no motion of the mercury column perceptible to the eye. The bulb was always carefully filled with hydrogen by flushing from the tank a number of times to remove the atmospheric air. It was found that use of hydrogen instead of air greatly improves the performance, both because of the better heat conductivity of the hydrogen, and because of the diminished resistance in the connecting capillary. Sluggishness of response due to viscous resistance in the capillary limits the sensitiveness of this device; if the size of the capillary is increased too much, error is introduced by fluctuations in room temperature because of changes in the volume of that part of the gas exposed to the temperature of the room.

In order to avoid danger from ignition of the propane vapors which might escape from the bath into the room, a small ventilating hood was built around the lower end of the press and connected with a ventilating fan. Evaporation was prevented as much as possible by the use of a fairly tight fitting cover over the propane bath, but this had to be removed during the manipulations incidental to freezing, so that during a run of several hours perhaps as much as 50 cm^3 of propane was lost by evaporation. This was replaced several times during the run from a special source of supply, so that the level of the bath was maintained approximately constant, an important point in order to avoid errors in the volume due to fluctuations in the temperature of the pipe. One anticipated source of danger was the explosion which might result from a mixing of propane with the liquid air if there was a rupture of the lower cylinder. Fortunately the lower cylinder remained intact during all the runs, but this source of danger was in any event minimized by surrounding the thermos flasks containing both propane and liquid air with heavy steel walls so that, if rupture of the lower cylinder did take place, only the small amount of liquid air which might happen to be in the cooling spiral would come in contact with the propane.

Before using propane I tried some of the non-inflammable liquids recommended for cryostats by the Bureau of Standards, which are described in International Critical Tables, vol. I, p. 61. It proved that although these might be practicable at the upper end of the temperature range as far as their behavior at that temperature only is concerned, they at once become of the viscosity of vaseline on the wall of the cooling spiral when the liquid air is sucked into the spiral, and for this reason were totally unfit for use in my particular form of cryostat.

Temperature was measured with a copper-constantan thermocouple, using a standard cell and Leeds and Northrup potentiometer, Type K, for the measurements of voltage. One junction was maintained at 0° C in a thermos flask filled with ice, and the other junction was immersed directly in the propane of the bath at a point very close to the wall of the pressure cylinder. The sensitiveness of the potentiometer corresponded to about 0.03°. The thermo-couple was calibrated at the boiling points of nitrogen and oxygen and at the subliming point of solid CO_2. The voltages at these temperatures were compared with those given by Adams for a copper-constantan couple in International Critical Tables, I, 57, and a smooth deviation curve was drawn through the points representing the difference of the readings. The temperatures corresponding to other voltages were obtained by a combination of Adams's tables with the deviation curve. The error in such a procedure should not be more than 0.05° at any point, which was sufficient for the purposes in hand. A second copper-constantan couple, connected to a sensitive millivoltmeter, served as a thermometer in giving a constantly visible indication of the temperature, but not with the accuracy of the potentiometer readings.

The bath temperature, except of course when boiling oxygen or nitrogen was used, fluctuated back and forth through an extreme range of 0.5° C with a period of about two minutes. The extreme temperatures were read several times during the course of a run and the mean taken as the true temperature. At the interior of the pressure cylinder the temperature fluctuations of the bath were to a large extent wiped out, but nevertheless, sometimes when both liquid and solid phases were present together, the temperature fluctuations were manifest in a small oscillation of pressure lagging almost 180° behind the temperature fluctuations of the bath. Under these conditions the mean temperature was taken as corresponding to the mean pressure. When only one phase was present the pressure fluctuations were too small to be perceptible.

In addition to the measurements with the apparatus just described of the coordinates of the melting curve and the changes of volume, it was necessary also to know the specific volume of the gaseous phase in the range of pressure and temperature involved. The reason for this is that the measured discontinuity in the motion of the piston gives the change of volume on freezing of that quantity of the solid which occupies a known volume, that is, the volume of the lower cylinder, under the given conditions, whereas what is thermodynamically significant is the change of volume per gram. A knowledge of a specific volume is therefore necessary. It has already been stated that no specific volumes are known in the range of pressures and temperatures involved here. However, it is very easy with this apparatus to make connection at any pressure between the volume at any temperature in the range below 0° C, and at temperatures in the range above 0°, merely by changing the temperature of the lower cylinder from the one value to the other and observing the amount by which the piston must be withdrawn to maintain pressure constant. Hence if the specific volumes are known over the requisite pressure range at some temperature above 0° C, the present apparatus readily supplies the additional information necessary. Now the specific volumes of nitrogen are known above 0° C, from the work of Amagat up to 3000 kg/cm^2, and from my own previous work above 3000. No such information exists for argon, however; it is true that I have measured the *changes* of volume above 2500 kg, but these results cannot be converted into specific volumes until the volume is known at some one fiducial point in the range. To obtain the one fiducial point another simple piece of apparatus was necessary. This consisted merely of a small steel bottle of known volume which could be filled with argon to a known pressure and sealed off from the source of supply. The total weight of the bottle filled with gas was then measured, and again after the gas had been allowed to escape. The bottle was made of a stainless steel sold under the trade name of "Alleghany 44." It is shown in Figure 1. The closure by the piece B was copper welded into place in an atmosphere of hydrogen, and was thus gas-tight. The capacity to the point C was then determined by weighing empty and filled with air-free distilled water. The interior volume was 1.26 cm^3. A steel capillary of 0.008 inch internal diameter and 0.120 inch external diameter was then soft soldered into the piece B, the threads being first tinned carefully both inside and out, and there being also an arrangement of steel retaining rings, not shown in the diagram, to prevent the extrusion of the soft solder by pressure. The other end of the steel capillary was connected to the high pressure apparatus by soft soldering into a cylinder shown in Figure 2, which replaces the lower cylinder of the freezing apparatus. The crux of the situation is the piece of Wood's metal A, contained in the connecting cylinder. In use, the bottle was maintained at 0° C and filled with argon to a measured pressure. The connecting cylinder and the upper 10 cm of the steel capillary were then raised to the boiling point of water, melting the Wood's metal A. An excess pressure of 500 or 1000 kg/cm^2 now forced melted Wood's metal into the capillary until it reached the cold part, where it froze. The connecting cylinder was now chilled, and the capillary cut off where it joins the cylinder, thus giving the bottle with gas sealed into it at known pressure. Weighing to the requisite accuracy was easily done

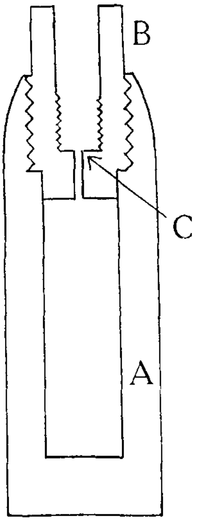

Figure 1. The steel bottle for obtaining a fiducial point on the p-v-t surface.

by attaching to the under side of the scale pan of a balance through a hole cut in the case. The actual filling was made at a pressure of 1070 kg/cm^2, and the weight of the gas was 1.030 gm. An attempt to get a second fiducial point from a filling at 1500 kg/cm^2 was unsuccessful because of leak around the soldered joint of the steel capillary. The interior of the steel capillary was found to be far from smooth; in places the cross section was roughly star shaped with sharp corners. This means that the absolutely tight sealing of the capillary with

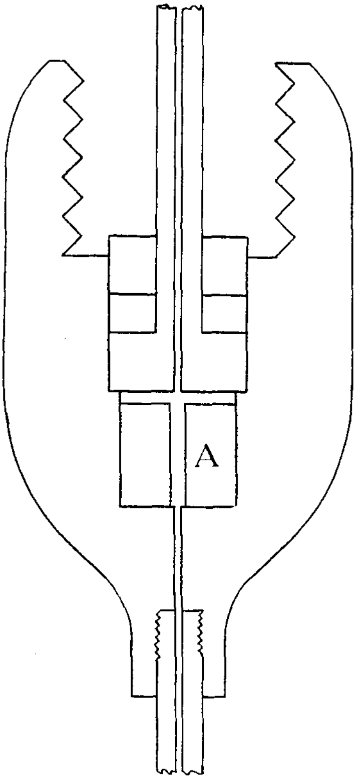

FIGURE 2. Shows the connecting piece through which the bottle of Figure 1 is filled. The piece of Wood's metal A is melted after filling, thus sealing the gas into the bottle.

melted Wood's metal was not the perfectly simple thing that would be suggested by the description above, but additional manipulation was necessary, pinching the capillary nearly flat in places with a heavy clamp, and remelting and resolidifying several times the Wood's metal between the pinched places. A perfectly tight seal can at once be tested by immersing the cut end of the capillary in water, and it was only after a number of attempts that such a perfectly tight seal was obtained.

There are a couple of small corrections to be applied; one for the thermal expansion of the steel of the bottle, for which the figure of the manufacturers (0.0000162 mean linear expansion between 20° and 100° C) was assumed, and a very small correction for the capacity of the capillary. The correction for the distortion of the bottle under internal pressure is too small to be appreciable.

The measurements with the bottle just described give a fiducial point at 1070 kg/cm^2, and the lowest pressure of my previous measurements was 2500. The interval between these two sets of measurements was spanned by making two sets of isotherms at room temperature, one with the same lower cylinder as that used in the melting measurements, and another with the same lower cylinder nearly filled with a known amount of steel. The difference of the piston displacements of the two isotherms gives the volume compression of the amount of gas occupying the volume of the steel, the various unknown factors, such as the effect due to the compression of the packings, dropping out when the difference is taken. By this means the new point at 1070 kg/cm^2 was connected with the previous work at 2500 and higher.

EXPERIMENTAL PROCEDURE.

The experimental procedure consisted mostly of perfectly straightforward adaptations and modifications of procedure used in previous measurements of phase change or of compressibility by the piston displacement method and need not be described in detail except for a few special points. The initial filling of the apparatus must be done in such a way as to get rid of most of the atmospheric air originally present, which otherwise will act as a dissolved impurity, depressing the freezing point and rounding the corners of the transition curve so as to obscure the true change of volume. In the case of nitrogen, of which a plentiful supply was available, this was accomplished by flushing out the apparatus three times from the original supply.

Since the pressure in the supply tank is of the order of 100 atmospheres, the original impurity is reduced by three flushings to 10^{-8} of the total, a wholly negligible amount. In the case of argon (because of its greater value), this procedure was modified by initially exhausting the apparatus to about 1/100 atmosphere, filling once with argon at 100 atmospheres, exhausting again to 1/100 and finally filling again with argon to 100, thus again reducing the proportion of atmospheric impurity to 10^{-8}.

The approximate location of the freezing curve was already known from the work of Simon. The freezing point was of course approached from the gas side, plotting the readings of piston displacement against pressure as each point was obtained. In this way the first beginning of freezing was at once caught. Special manipulation was now necessary in order to fill the lower cylinder with the solid phase and prevent freezing in the connecting pipe, which would have led to an incorrect and too small value for the change of volume. This was accomplished by lowering the bath from around the lower cylinder until only the lower part of the cylinder was dipping in the bath liquid, and then pushing the piston in by a number of small steps, perhaps 10 or 12 altogether, and at the same time raising the bath back until the cylinder was again completely immersed and also the connecting pipe up to the former mark. In this way the lower cylinder was forced to freeze solidly full from the bottom up. After complete freezing had been accomplished, pressure was raised about 200 kg beyond the freezing point. Care must be taken not to push pressure too far beyond the freezing point or else the plug of solid in the pipe will yield, transmitting pressure to the solid in the cylinder, so that the change of volume measured will be that between the gas at the transition pressure and the solid at a somewhat higher pressure, which would give too large a change of volume. Readings were now made with decreasing pressure, perhaps at 40 kg intervals above the freezing point, several in the two phase region with varying proportions of the two phases, and then several in the gaseous phase, locating the first reading in the gaseous phase as close as possible, usually within 40 kg, of the lower corner of the discontinuity, so as to minimize error by making only a short extrapolation necessary. It is obvious that having once filled the lower cylinder full with the solid phase, no such precautions were necessary in lowering pressure as in raising it, and these readings could be made rapidly. The small size of the apparatus and increased thermal conductivity at low temperatures much facilitates the procedure compared with previous transition measurements at higher temperature, and the whole series of readings with decreasing pressure could be made in less than an hour. Both the pressure-temperature coordinates of the melting curve and the change of volume were taken from the readings with decreasing pressure, these being more reliable than the readings with increasing pressure.

The discontinuity in piston dipslacement given directly by the readings does not yield at once the change of volume on melting of the amount of solid which fills the lower cylinder, but includes also the thermal expansion of the gas on passing from the temperature of the lower to that of the upper cylinder. Because of the large temperature ranges, this correction is considerable. The full details by which the correction was determined need not be described here. The general method, as already indicated, was to describe isotherms at various temperatures over the range of pressures involved, the difference of the isotherms giving almost directly the thermal expansions necessary. These isotherms were checked after a cycle of pressure and temperature changes by returning to the initial point. This check was almost always highly satisfactory, there being no evidence of leak, or of penetration of the gas into the steel, or permanent deformation of the cylinder. Only once was there a slight and temporary leak at the highest pressure; the character of the plot made so obvious the exact place where this had occurred that small corrections could be easily applied to it, so that it was not necessary to discard the run.

The parameters of the gaseous phase as such were determined only in so far as they were necessary to characterize completely the transition data, but nevertheless a considerable amount of information was thus incidently obtained of the *p-v-t* surface in regions not previously explored. This data is tabulated in the following, not at regular temperature intervals, which would have involved interpolations and extrapolations which would perhaps not have been justified, but very nearly in the form in which it was obtained. I hope that at some time in the future this same apparatus may be used to give more systematic information about the *p-v-t* surface in this region.

DETAILED PRESENTATION OF DATA.

Nitrogen. The nitrogen was obtained from a cylinder of 99.90% purity. I am indebted for this to the special courtesy of the Research Department of the Air Reduction Company. The labels as commercially supplied indicating the purity of nitrogen are highly misleading.

Thus the true meaning of a label "99.90% pure" on a commercial tank is that the oxygen content has been tested and found to be 0.10%. In addition to oxygen, there is of course a considerable impurity of argon in nitrogen obtained from atmospheric sources as is this, and this impurity is not at all indicated by the label. However, my cylinder was specially provided, and I have the statement of the Research Department that the actual nitrogen content of my sample was 99.90%. As always in making these transition determinations, the data themselves give internal evidence, by the sharpness of the transition, of the degree of purity, and the transitions were in fact in the final series of runs always gratifyingly sharp. In some of the early runs, however, sharp transitions were not always obtained, when various difficulties were encountered in sufficiently flushing out the atmospheric air originally filling the apparatus. Not only were the corners sometimes rounded under these conditions, but after freezing had once taken place the impurities sometimes segregated, and did not immediately remix, by diffusion, when melting took place, so that there was the appearance of a discontinuity in the gaseous phase, due to the melting of the segregated impurity, superposed on the main transition. One might in this erroneous way receive the

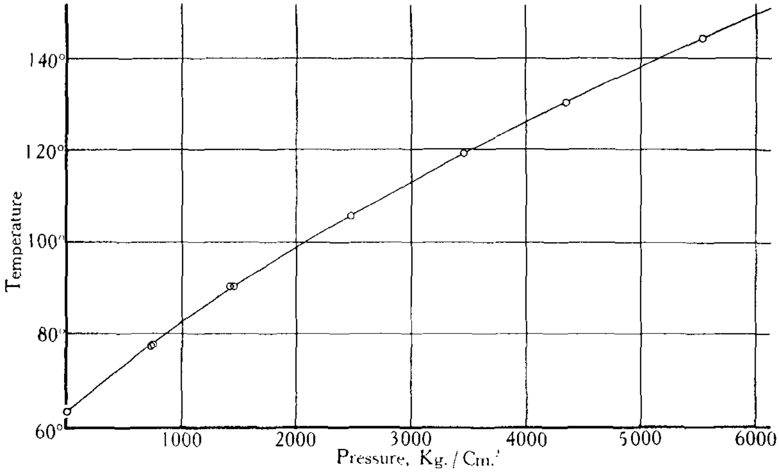

Figure 3. The melting temperature of nitrogen in degrees Absolute as a function of pressure.

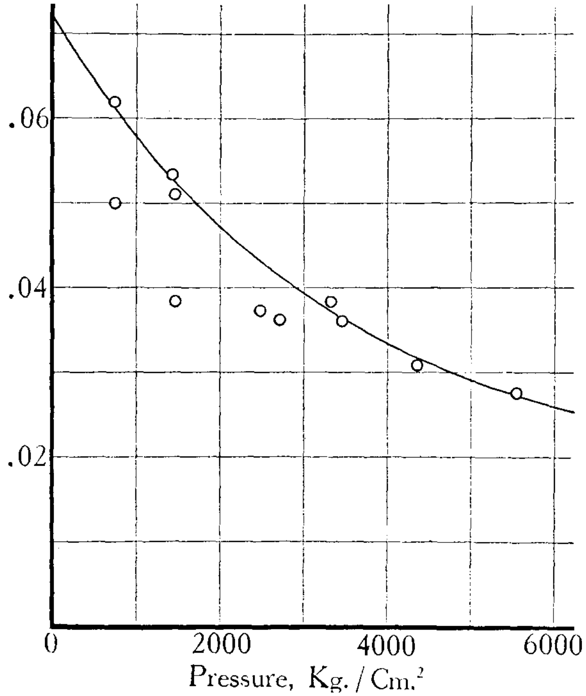

FIGURE 4. The change of volume of nitrogen on melting, in cm^3 per gm, as a function of pressure.

impression that there were degradation phenomena in the gaseous phase at high pressure and low temperature.

In all, runs were made with ten different fillings of the apparatus, of which a few were completely discarded because of either insufficient purity, as shown by the rounding of the corners of the transition, or because of imperfections in various parts of the apparatus, such as the temperature measurements or measurements of piston displacement, before the final details of the apparatus had been worked out. There were about six fillings which gave satisfactory results, either for the transition data or for the various isotherms. The experimental points for the pressure-temperature coordinates of the melting curve are shown in Figure 3, and the changes of volume in Figure 4. The p-t points are sufficiently regular, but one could wish that some of the Δv points had been better. This doubtless means that, in spite of the precautions, the lower cylinder was not always completely filled with the solid phase. There are probably two reasons for this. In the first place, solid nitrogen seems to have considerable mechanical strength, so that, if the connecting pipe is once plugged with the solid, considerable excess pressure is necessary to force the plug through and build up the proper pressure in the lower cylinder. On several occasions, when the manipulations of lowering the cylinder back into the bath and simultaneously building up the pressure were not made with great care, very nearly steady conditions were attained at pressures several hundred kilograms beyond the transition pressure at a piston displacement corresponding to only partial completion of the transition. That is, the pipe was plugged, and the plug was yielding with extreme slowness because of its mechanical strength. The second reason is probably connected with the fact that nitrogen apparently does not subcool under the conditions of the experiment, for freezing was always observed to start when pressure exceeded the transition pressure by the smallest observable amount. Since the pressure increases are transmitted through the pipe, a nucleus of solid may well have started to form in the pipe before freezing started in the cylinder itself, so that the formation of a plug is especially easy. One must not from this draw the conclusion that nitrogen will not subcool under any conditions; it is quite consistent with my previous experience that it might subcool when contained in a glass vessel, for instance, although it may not subcool in contact with steel.

The most probable errors in Δv appear to be in the direction of too small values, so that in Figure 4 the low lying points were entirely disregarded in drawing the curve.

In Table I are shown the transition data, taken from the data of figures 3 and 4, smoothed and tabulated at intervals of 1000 kg/cm^2. The freezing point at atmospheric pressure was obtained from International Critical Tables. Table I also contains values of $\frac{d\tau}{dp}$, obtained from a plot of the first differences of temperature against pressure, and finally the latent heat of the transition, L, calculated by Clapeyron's equation, $\frac{d\tau}{dp} = \frac{\tau\Delta v}{L}$, from the other data of the table. The last significant figure in the latent heat is obviously in great doubt.

A most important point to be settled with regard to the melting curve and the data of Table I is whether the melting parameters determined by these experiments refer to α-nitrogen, (low temperature

TABLE I.

MELTING PARAMETERS OF NITROGEN.

Pressure kg/cm^2	Temp. Abs.	$\frac{d\tau}{dp}$	ΔV cm^3/gm	Latent Heat kg cm/gm
1	63°.2	.0209	.072	218
1000	82 .3	.0176	.058	271
2000	98 .6	.0153	.047	302
3000	113 .0	.0135	.040	334
4000	125 .8	.0124	.033	335
5000	137 .8	.0117	.029	342
6000	149 .2	.0112	.026	346

modification at atmospheric pressure) or to β-nitrogen (high temperature modification). At atmospheric pressure the transition temperature between the two modifications is 35.5° K. The melting curve which is measured at low pressures, as for example in the recent work of Keesom and Lisman up to 110 kg/cm^2, is obviously that of the β modification. If the high pressure coordinates given above are for the α modification, then there must be a triple point on the melting curve, with discontinuity in direction. The lowest pressure of my measurements was 750 kg; it seems that the assumption of a triple point above this pressure is not consistent with the experimental accuracy. If there is a triple point, therefore, it must be between 110 and 750 kg. In this range there are only the measurements of Simon, but when these are plotted on a large scale it appears that there is too much irregularity to settle the point. The argument must therefore be more or less indirect. If the thermodynamic parameters for the transition from α to β were accurately known, the slope of the transition line could be computed and the question settled. This unfortunately is not the case; the latent heat of the transition is accurately known from the work of Giauque and Clayton,[5] but the values for the volume of the two solid modifications are very conflicting. Thus Dewar[6] gives for the density of the solid at 63° K 0.879 gm/cm^3, Simon finds 0.95_6, and Keesom and Lisman find 0.947 by calculation from their own $\frac{d\tau}{dp}$ and the latent heat of Giauque. There are X-ray measurements of the density of β-nitrogen: 0.995 at 39° K by Ruhemann[7] and 0.982 at 45° by Vegard.[8] The crystal structure of α-nitrogen has been determined at liquid hydrogen temperature by de

Smedt, Keesom and Mooy,[9] who find that the structure is probably tetragonal with four atoms in the cell and density of 1.03. It would seem probable therefore that the density of α-nitrogen is greater than that of β-nitrogen at the transition point, which means that the transition line rises, and that therefore a triple point on the melting line is a possibility. Further indirect evidence is contained in the data of Keesom and Lisman for the melting parameters up to 110 kg. Their initial slope is $\frac{d\tau}{dp} = 0.0222$ against 0.0209, my extrapolated value by drawing a smooth curve with no triple point, and their Δv at atmospheric pressure, 0.092, is much higher than my 0.072, obtained by smooth extrapolation. These discrepancies are evidence of something the matter, but the disturbing feature is that the discrepancies at first appear to be in the wrong direction to be accounted for by a triple point, since my latent heat should be the sum of the melting heat of β and the transition heat and therefore larger than the heat of Giauque, and my Δv should be the sum of the Δv of liquid $-$ β and $\alpha - \beta$ and therefore larger than the value of Keesom and Lisman, instead of smaller. It appears to me that the solution may be found in a very rapid variation of the properties of β-nitrogen in its domain of stable existence. That is, the slope $\frac{d\tau}{dp}$ must drop rapidly along the melting curve, and its Δv must also fall rapidly. As far as the slope of the melting curve goes this is consistent with the data of Keesom and Lisman, for the formula by which they reproduce their results has initially a slope 6% greater than mine, which means that initially their temperatures lie above my smooth curve, but at 2000 kg their formula gives a melting temperature 6.7° lower than mine. A bit of confirmatory evidence is that at low pressures the temperatures of Simon are a trifle higher than mine, whereas at high pressures they become rapidly lower. It seems, therefore, probable to me that there is a triple point below 750 kg, that there is rapid variation in the properties of β-nitrogen, and that the parameters of the melting curve given in Table I are for the melting of the α modification. This solution cannot be regarded as entirely satisfactory, however, and must wait for final confirmation for accurate measurements of the melting parameters in the pressure range below 750 kg, and for a good determination of the difference of density of the α and β modifications at the atmospheric transition point.

TABLE II.

VOLUME OF 1 GM OF NITROGEN.

Pressure kg/cm²	Volume, cm³				
	+23°.5 C	0°	−50°	−100°	−140°
3000	1.2374	1.2069	1.1422	1.0754	1.0226
4000	1.1615	1.1391	1.0881	1.0327	.9876
5000	1.1061	1.0870	1.0451	.9997	.9613
6000	1.0652	1.0487	1.0117	.9729	.9412

In Table II are given the volumes of the gas at regular pressure and temperature intervals. This table is based on my previous values for the volume at pressures above 3000 kg/cm² at 68° C, reducing these values to other temperatures by means of the thermal expansions determined in this investigation. My previous work, in turn, was based on the fiducial volume of Amagat[10] at 3000 and 68°. Amagat also determined the thermal expansion at 3000 kg. His value for the mean expansion between 0° and 68° at 3000 kg differs by 2% of itself from the value found by me in the present investigation. The volumes of the gas given in Table II are not sufficient for all the reductions necessary in computing the parameters of Table I, since they do not extend below 2000 kg. Additional information needed at the lower pressures was as follows: at the freezing point at boiling nitrogen temperature, that is, at 745 kg/cm² and 77.5° K, one gram of gas occupies 1.138 cm³. At the boiling oxygen freezing point, that is, at 1472 kg/cm² and 90.25° K one gram of gas occupies 1.123 cm³.

Table II gives the means for finding the volume of the gas at various points of the freezing line; there were direct experimental values at three higher pressures as well as at the points just mentioned. The following appear to be the best values for the volume of one gram of the gaseous (amorphous) phase at pressures on the melting curve of 1, 1000, 2000, 3000, 4000, 5000, and 6000 kg/cm² respectively: 1.140, 1,137, 1.094, 1.010, 0.980, 0.962, and 0.956. The sudden drop and point of inflection between 1500 and 3500 is unexpected, but the curve as given passes exactly, to the last significant figure, through my five experimental points and the point at atmospheric pressure determined by Baly and Donnan as quoted in Smithsonian Tables. An additional experimental point at 2500 to clinch matters would have been desirable, but unfortunately two attempts to put a point here were frustrated by leaks. The curve for the volume of the solid phase along the melting line may be found at once from the data just given and from the data of Table I, the shape of the curve is very much like that for the shape of the amorphous phase, except that the variations are not so pronounced.

Argon. The argon was obtained from the Cleveland Lamp Division of the General Electric Company, to whom I am much indebted. It was purified by a process recently developed for use in directly filling lamps without further purification. The impurity is stated to be only 0.1%. I used it without further purification; the transitions were sharp, indicating sufficient purity.

The measurements on argon were made after the apparatus had been perfected and after experience with the manipulations had been gained by the work on nitrogen, so that not so many runs were necessary; six fillings in all were made of the high pressure apparatus, and in addition several fillings of the bottle in order to get a fiducial point on the p-v-t surface.

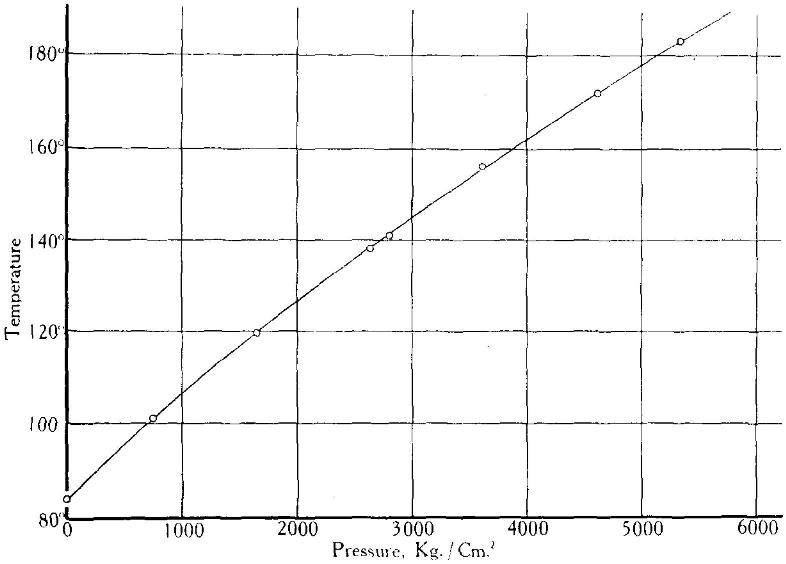

FIGURE 5. The melting temperature of argon in degrees Absolute as a function of pressure.

The experimental *p-t* points on the melting curve are shown in Figure 5 and the experimental values of Δv in Figure 6. It will be seen that in general the Δv points lie much more smoothly than for nitrogen. Neither of the reasons suggested for the irregular results of nitrogen seem to be operative in the case of argon. In the first place, argon was several times observed to subcool, excess pressures of 100 kg or more being possible before freezing takes place. As already suggested, this characteristic would tend to result in the formation of the first nucleus of the solid in the cylinder itself rather than in the connecting pipe, with less likelihood of a plug of solid in the pipe.

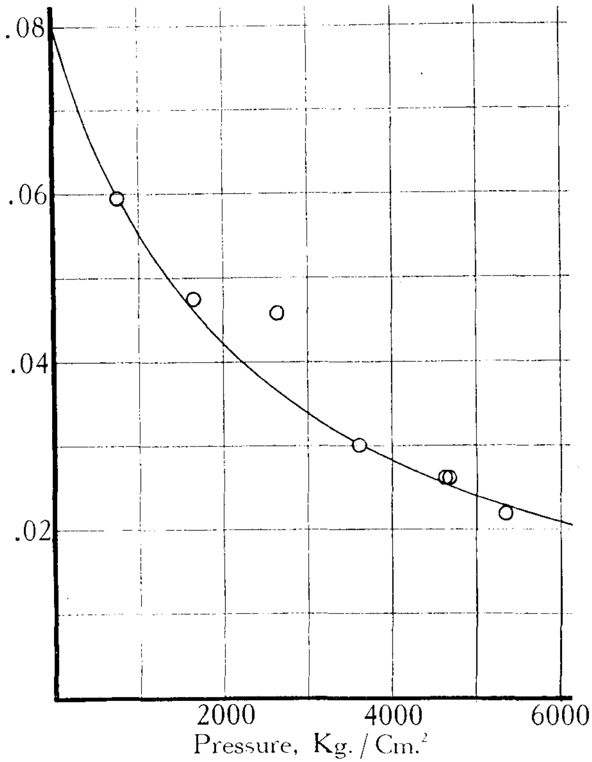

FIGURE 6. The change of volume of argon on melting, in cm^3 per gm, as a function of pressure.

In the second place, the mechanical strength of solid argon is apparently not as high as that of solid nitrogen, and no phenomena were observed with argon which would suggest the plugging of the pipe. In fact, on one occasion the change of volume on freezing was measured without taking any of the regular precautions to ensure freezing from the bottom of the lower cylinder, and the point thus obtained lay smoothly on the curve with the others.

The melting parameters, at regular intervals and smoothed, are given in Table III; the melting point at atmospheric pressure was taken from International Critical Tables.

TABLE III.

MELTING PARAMETERS OF ARGON.

Pressure kg/cm^2	Temp. Abs.	$\frac{d\tau}{dp}$	ΔV cm^3/gm	Latent Heat kg cm/gm
1	83°.9	.0238	.0795	280
1000	106.4	.0211	.0555	280
2000	126.3	.0192	.0425	279
3000	144.9	.0178	.0340	277
4000	161.9	.0165	.0280	275
5000	177.8	.0155	.0240	276
6000	192.9	.0146	.0210	277

The volumes of the amorphous phase, at regular pressure intervals and various odd temperatures determined by the accidents of the thermostat settings for the transition measurements, are given in Table IV. The values at 55° C are taken over directly from previous work, it now being possible to give the absolute volumes instead of only the volume changes, which alone was possible previously.

Table IV provides the means by which the volume of the amorphous phase may be found at various points on the melting curve. There are also approximate experimental values for these same quantities; the experimental point at 750 kg/cm^2 lies too high to fit in with the other points and the known value at atmospheric pressure; the experimental points at higher pressures lie fairly well on a smooth curve. The following seem to be the best values for the volume in cm^3 of 1 gm of the amorphous phase at various points on the melting curve: 1 kg, 0.702 cm^3; 2000 kg, 0.656 cm^3; 4000 kg, 0.638 cm^3; 6000 kg, 0.628 cm^3. The corresponding values for the volume of the solid are: 0.622,

TABLE IV.

VOLUME OF 1 GM OF ARGON.

Pressure kg/cm²	Volume, cm³								
	+55° C	+25°	0°	−90°.0	−101°.4	−117°	−135°.1	−153°.5	−171°.9
700		1.262	1.179						
800		1.175	1.105					.724	.690
900		1.110	1.048						
1000		1.060	1.006					.697	
1100		1.020	.970						
1200		.989	.943						
1300		.962	.920					.677	
1400		.938	.899						
1500		.916	.880						
1600		.898	.864					.657	
1700		.883	.852						
1800		.870	.840						
1900		.857	.828						
2000	.880	.846	.818						
2500	.831	.808	.785		.687		.653		
3000	.797	.773	.753	.671	.667				
3500	.772	.751	.733	.661	.656	.638			
4000	.748	.729	.713	.650	.642				
4500	.730	.712	.697	.641	.632				
5000	.712	.695	.681	.631					
5500	.698	.682	.669	.624					
6000	.685								
7000	.663								
8000	.645								
9000	.630								
10000	.617								
11000	.607								
12000	.596								
13000	.588								
14000	.580								
15000	.573								

0.613, 0.610, and 0.607. This approximate constancy may be of some theoretical significance.

DISCUSSION.

A comparison of my *p-t-v* values of the gas with those of other observers is not possible, for there are no other determinations in this range; the only other values for the freezing parameters are those of Simon and collaborators for the *p-t* coordinates. Simon's melting curves for both nitrogen and argon run mostly below mine, that is, at a given pressure his melting temperature is lower than mine. For argon the discrepancy increases from 0 at atmospheric pressure to a maximum of about 2.5° at 1400 kg, between 1400 and 3400 the discrepancy is roughly constant, becoming less, if anything, at the higher pressures. For nitrogen the discrepancy is more serious. Up to 1400 his curve lies slightly higher than mine, by not more than 0.2° or 0.3°, but at 1400 it crosses, and from here on the divergence increases rapidly with increasing pressure, becoming more than 6° at 4900. The discrepancy is in the direction that would indicate impurity in Simon's material, but I believe that this is not the explanation and that the reason for the discrepancy can be found in Simon's method. This was the method of the stopping of a capillary tubing first used by Keesom[11] in finding the freezing curve of helium. A capillary tube filled with the gas connects at either end with a pressure gauge, the central part of the capillary being maintained at the temperature at which the freezing pressure is to be determined. Pressure is increased by pushing a plunger into a cylinder connected to one end of the capillary, resulting in a rise of pressure in both gauges as long as the substance remains fluid, but when the substance freezes the capillary is plugged and only the one gauge responds to a further decrease of volume. A source of error in the method, apparently not discussed either by Keesom or Simon, is the fact that the plug of solid in the capillary must be under a shearing stress, and it is known by thermodynamics that the freezing temperature is always depressed by a shearing stress by an amount proportional to the square of the stress and to the absolute temperature. The fact that the discrepancies are markedly greater with nitrogen than with argon fits in perfectly with the observation made above that the pipe plugs much more easily with nitrogen than argon, involving a greater mechanical strength in the solid nitrogen and consequent greater shearing stress in it. The rapid increase of the discrepancy in nitrogen at high pressures is also consistent with this suggestion; the discrepancy would increase because of the increased viscosity or shearing strength to be expected in solid nitrogen in virtue of the increasing pressure, and it would also increase because of the absolute temperature factor in the thermodynamic formula. On the other hand, there would be a decreasing tendency because of the decreased strength to be expected at higher temperatures; in view of other experience at high pressures I would expect the first tendency much to preponderate. It would be an easy matter to find whether this is actually an important source of error if experiments by the method of Keesom are repeated in the future;

if the effect is unimportant, the freezing pressure should be independent of the diameter of the capillary, whereas if the effect is important, the apparent freezing temperature should increase as the diameter of the capillary increases. Apparently the size of the capillary was not varied in previous experiments; the diameter of Simon's capillary was only 0.15 mm.

The fundamental question raised by this investigation with regard to the existence of a critical point, crystalline-amorphous, must already have been answered by the reader from an inspection of Tables I and III. If there is a critical point, the curves of latent heats and volume differences must be such that they will extrapolate to a common vanishing point. For argon the latent heat is almost exactly constant, whereas for nitrogen it increases, comparatively rapidly at first (which may be an effect of the disregarded triple point), but it also is approximately constant between 3000 and 6000 kg/cm^2. The volume differences on the other hand decrease, but the curve is convex toward the pressure axis in such a way as not to indicate vanishing at any finite pressure. Furthermore, if the changes of volume and the slope of the melting curve, $\frac{d\tau}{dp}$, are plotted against temperature instead of pressure, in every case the curve will be found to be convex toward the temperature axis. In all these respects the behavior of nitrogen and argon is not different from that of all other substances whose melting parameters under pressure have been determined, and there is still absolutely no evidence which would lead one to expect the existence of a critical point or to expect that the melting curve does otherwise than rise to indefinitely high pressure and temperature, with a curvature becoming continually less, a difference of volume between the two phases becoming continually smaller, and a latent heat tending on the whole to remain constant or to increase.

In retrospect it is a little difficult to see why a permanent gas should be expected to give any more valuable evidence as to the character of the melting curve than other substances. Simon makes the point that in the case of helium, which unfortunately could not be investigated here, the critical temperature, gas-liquid, has been exceeded in his measurements by a factor of 8, whereas previously the maximum excess was only 20%, in the case of CO_2. But what the precise significance of this is does not appear in the absence of any theory indicating a connection between the phenomena of passage from vapor to liquid and passage from amorphous to crystalline phase, and in any event it does not appear why it should be more informing to exceed the critical temperature 8 fold than to exceed the critical pressure 165 fold, which had already been done. In fact, the great difference between the relative rôles played by pressure and temperature on the vaporization and the melting curves, as shown by the difference between the factors 8 and 165, should itself indicate a vital difference between the phenomena of vaporization of the liquid and of crystallization of the liquid.

There are a number of minor points which may now profitably be discussed. The latent heats of melting at atmospheric pressure given in Tables I and III, which were obtained by extrapolation from the last experimental point at 750 kg/cm^2, may be compared with the directly determined values of other observers. For nitrogen my extrapolated value is 218 kg cm/gm against 259 of Giauque. For argon my extrapolated value is 280 kg cm/gm against 287 of International Critical Tables. It may be mentioned that all my computations and extrapolations were made before these previous values were consulted, and that no adjustment was made afterward. The better agreement in the case of argon is, doubtless, to be explained in part by the better values for Δv which it was possible to obtain for argon, and in the case of nitrogen there is the unsettled point of a possible triple point. I do not believe, however, that all the discrepancy can be laid on my Δv values, but I believe that there may be error in the previous values at atmospheric pressure. Simon comments on the well known inaccuracy on the density of the solid phase at atmospheric pressure, a datum which enters the latent heat.

The difference of energy, ΔE, between liquid and solid is of interest as well as the latent heat. The energy difference is obtained by subtracting from the latent heat the mechanical work during melting, or $p\Delta v$. The term $p\Delta v$ is given in Tables I and III. Plotted against pressure or temperature it rises continuously, concave toward the pressure or temperature axis, with continually decreasing curvature. The ΔE curve has much the same character as the Δv curve, falling with increasing pressure or temperature, but convex toward the axis in such a way as not to indicate vanishing at any finite pressure or temperature. The character of the $p\Delta v$ curve also gives some insight into the behavior of Δv itself as a function of pressure. If Δv vanishes at a finite pressure or temperature, the $p\Delta v$ curve must cross the axis at the corresponding point and there is no indication of this.

Furthermore, if Δv vanishes at infinite pressure, and if the $p\Delta v$ curve continues to rise, as it does in the experimental range, then Δv must vanish with infinite pressure less rapidly than it would if the relation between p and Δv were of a simple hyperbolic type.

In setting up a theory of the melting curve and its ultimate course it would seem that some significance should be attached to the volumes of liquid and solid phases along the melting curve. Such information has been available in only a few cases hitherto, there being very few substances whose p-v-t surfaces have been determined for both liquid and solid phases. In the case of water and mercury it was known, however, that volume of both liquid and solid decreases with rising temperature and pressure along the melting curve. We now add to this the information that the volumes of nitrogen and argon also decrease. It would therefore appear not unlikely that this may be the general state of affairs. In fact Simon drops the remark that the volume of the liquid "must" decrease along the melting curve. Such a state of affairs is, doubtless, consistent with our rough general expectations, because as the disorienting effect of temperature increases it would seem natural that the molecules should have to be brought into closer contact to induce crystallization. But this can be only a partial picture, because we know from thermodynamics that freezing is not produced by any condition in the liquid phase alone, but takes place only when there is a proper relation between both phases, a consideration which does not enter the crude picture just presented. I believe that in the absence of any general theory the expectation that the volume of the liquid phase *always* decreases along the melting curve is premature. In fact, the data obtained above suggest that theory might take as a rough first approximation the assumption that the volume of the liquid is constant along the melting line.

Turning now to the new data for the gaseous phase alone, the determination of the volume of argon at one fiducial point makes it possible to compute the p-v values at high pressures using data previously found. The relative pv values at 0° C and 55° C are given in Table V. In computing these values, the volume of 1 gm of argon at 1 kg/cm^2 at 0° C was taken to be 580.3 cm^3, and the perfect gas law was assumed to hold at atmospheric pressure between 0° and 55°. At high pressures the curve of pv against pressure is normal, being slightly concave toward the pressure axis. Compared with nitrogen at 68°, hydrogen at 65°, and helium at 55°, the only other gases for which pv is known at high pressures and which will be found in Figure

TABLE V.

RELATIVE VALUES OF PV FOR ARGON.

Pressure kg/cm²	PV 0°	PV 55°	Pressure kg/cm²	PV 0°	PV 55°
1	1.000	1.00	8000		7.40
1000	1.733		9000		8.14
2000	2.818	2.52	10000		8.85
3000	3.89	3.43	11000		9.58
4000	4.91	4.29	12000		10.26
5000	5.87	5.10	13000		10.97
6000		5.89	14000		11.65
7000		6.65	15000		12.33

4 of my previous paper,[12] pv for argon at 55° is between that of nitrogen and hydrogen, and is roughly twice that of helium. At pressures below 2000 kg/cm², pv for argon starts out by being convex toward the pressure axis; this convexity is much more marked at 0° than at 55°, and is of course a result of the fact that at 0° argon is relatively much nearer its critical temperature than the other gases at the temperatures mentioned.

The data contained in Tables II and IV give much better values for the thermal expansion of nitrogen and argon than were obtained in my previous measurements, which were only very rough, and in fact I did not venture to give the values in detail. One check on the values now obtained has already been mentioned, namely that at 3000 kg/cm² my thermal expansion of nitrogen agrees within 2.5% with that of Amagat. At higher pressures there are no previous values for comparison. It is seen that thermal expansion regularly decreases with increasing pressure and is less by a factor of several fold than it would be for a perfect gas. In fact it is smaller than for many liquids, such as alcohol, under normal conditions. Thus for nitrogen the thermal expansion at 0° C at 3000 kg/cm² is less by a factor of 3.4 than for a perfect gas, and at 6000 is less by a factor of about 5.5. Similarly, the thermal expansion of argon at 0° at 2000 is less by a factor of 2.82 than for a perfect gas, and at 5000 is less by a factor of 5.9. pv, on the other hand, differs more from the perfect gas values for nitrogen than for argon. This means that the compressibility of nitrogen differs more from the perfect gas value than does that of argon, but its thermal expansion differs less. The relatively high thermal expansion of nitrogen, as compared with that of argon, tends to become more marked when extrapolated to higher pressures. It is known that a small thermal expansion means a law of force between the molecules which is nearly linear, exact linearity leading to zero thermal expansion, so that the forces in nitrogen at high pressures are not so nearly linear as in argon. This might be expected of a diatomic substance as compared with a monatomic one.

It is of interest to find the change of internal energy with pressure along an isothermal of the two gases at high pressures. This is given by the formula $\left(\frac{\partial E}{\partial p}\right)_\tau = -\tau\left(\frac{\partial v}{\partial \tau}\right)_p - p\left(\frac{\partial v}{\partial p}\right)_\tau$. $\left(\frac{\partial E}{\partial p}\right)_\tau$ is zero for a perfect gas, but for condensed phases is initially negative, and changes sign at some high pressure. The pressure of the change of sign is the pressure at which the attractive and repulsive forces are in balance. A rough calculation shows that in the case of nitrogen the pressure of reversal is between 4000 and 5000 kg/cm^2 at room temperature, and between 5000 and 6000 at − 120° C. The volume at the reversal point is markedly higher at the higher temperature. The minimum of E is very flat however, and its exact location is therefore subject to experimental error, so that possibly the variation just stated in the pressure of reversal with temperature is not significant. For argon, on the other hand, the reversal has not yet been reached in the range covered in Table IV. It is also known that the reversal point of helium must occur at pressures probably above 15000 kg/cm^2 at 55°; this suggests a possible essential difference between diatomic and monatomic substances.

I am indebted to Mr. Charles Chase for assistance in setting up the apparatus, and for financial assistance to the Milton Fund of Harvard University and the Rumford Fund of the American Academy of Arts and Sciences.

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Proceedings of the American Academy of Arts and Sciences.

Vol. 70. No. 2.—March, 1935.

OBSERVATIONS ON THE BEHAVIOR OF ANIMALS DURING THE TOTAL SOLAR ECLIPSE OF AUGUST 31, 1932

By William Morton Wheeler, Clinton V. MacCoy, Ludlow Griscom, Glover M. Allen, and Harold J. Coolidge, Jr.

(Continued from page 3 of cover.)

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Proceedings of the American Academy of Arts and Sciences.

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By William Morton Wheeler, Clinton V. MacCoy,
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Received October 8, 1934. Presented February 13, 1935.

INTRODUCTION.

By Harold J. Coolidge, Jr.

A search of astronomical records of total eclipses of the sun has revealed occasional references to unusual behavior of bird and animal life that has been attributed to the effect on them of the total eclipse. The earliest record that the Committee has come across is that of the total eclipse in 1544 when a note was added mentioning the fact that "birds ceased singing," and again in 1560 there is a statement that "birds fell to the ground."

The historical study of this question produced scattered observations on the behavior of birds, mammals, some insects, and plants. In most cases these observations were made by astronomers who were primarily occupied with observing the eclipse, and only in the case of cloudiness was there much time to note the behavior of animals, and then only when they had the good fortune to be in a situation where any animals were close by.

The occurrence of the eclipse of August 31, 1932, at three-thirty (standard time) in the afternoon with a zone of totality extending through a considerable farming district of Maine, New Hampshire, and northeastern Massachusetts gave a splendid opportunity for a study of the effect of a total eclipse on the behavior of wild and domestic animals. The curiosity of the public, as well as of scientists, had been aroused on this subject by the scattered reports from previous eclipses and it was with the purpose of making a more careful and comprehensive study that the eclipse behavior committee of the Boston Society of Natural History was organized. This committee included ten members, as follows: Glover M. Allen, Thomas Barbour, Harold J. Coolidge, Jr., Ludlow Griscom, F. H. Kennard, Clinton V. MacCoy, George H. Parker, Charles H. Taylor, William M. Wheeler, and Edward Wigglesworth. In the following account

Professor Wheeler has dealt with the behavior of insects, Dr. MacCoy that of cold-blooded vertebrates, Mr. Griscom that of birds, Professor Allen and Mr. Coolidge that of mammals.

The problem of obtaining a large number of observations from varied localities was possible only through the active help and coöperation of many newspapers, particularly those enjoying a wide distribution in New England. The Committee planned to make a study of observations procured in three ways.

First: by the general public, including anyone who was sufficiently interested to send in a record of what he or she saw.

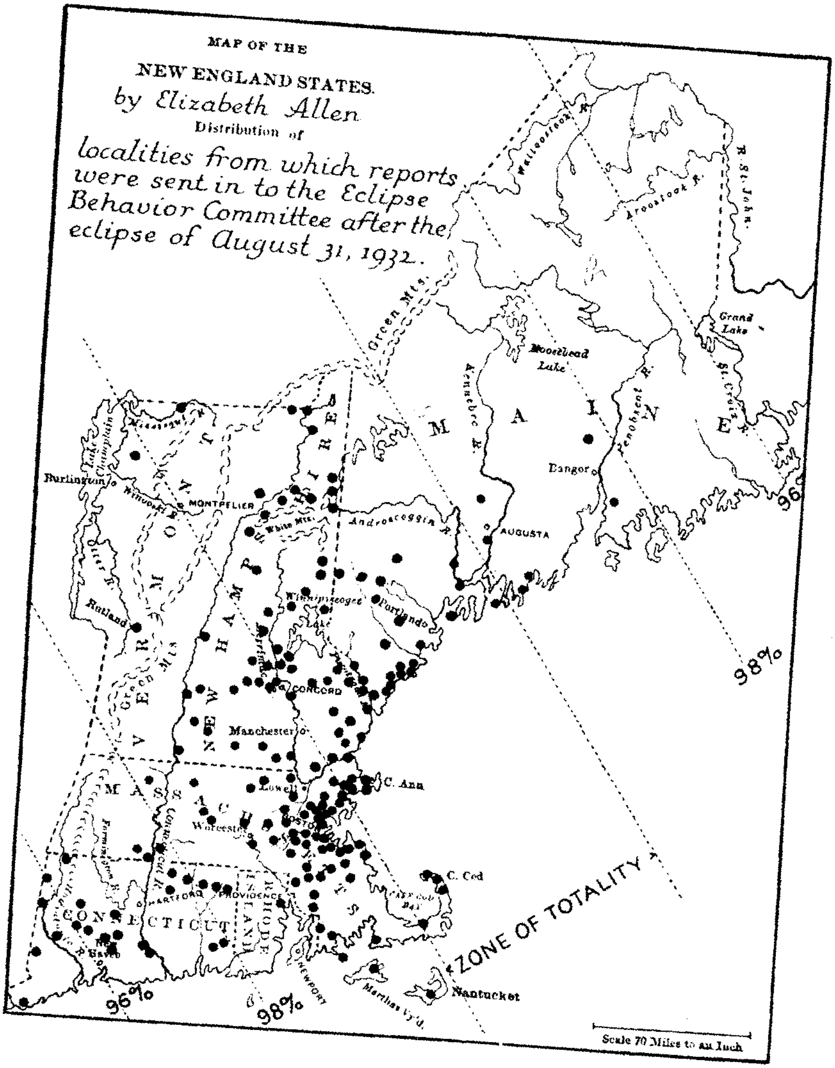
Second: an official report by the game wardens of various states.

Third: by reports submitted by naturalists who occupied definite places in the zone of totality, especially adapted for the observation of some group of animal or insect life in which they were particularly interested.

The returns from these different methods of observation were very gratifying, and only a small number had to be discarded for one reason or another. These observations were divided into six groups, namely, birds, mammals, insects, fishes, reptiles, and flowers. The observations under each group were entered on a separate card with the notation of the observer, time, place, and behavior. Also a map was prepared of each group of observations, showing the exact localities where the records had been made. This material was then assigned to different scientists who had been particularly chosen to make a study of it, using in each case a unified system of handling the material. Acknowledgements were also sent out to the people who so kindly wrote in their observations.

Inevitably the editing and study of these records and the preparation of final reports by the men working on each group have taken a considerable time. Most of the important findings are recorded in the following paragraphs.

The Eclipse Behavior Committee takes this occasion again to thank those people of New England who took the trouble to make observations and send reports of them to the Secretary. Its thanks are due also to the following newspapers: The Boston Globe, The Boston Herald and Traveler, The Boston Transcript, The Boston Post, The Boston American, and the Christian Science Monitor, all of which, by the wide publicity they gave this committee, with important space often on the front page and mention in the radio broadcasts, greatly helped to spread the news of the survey. The


MAP OF THE
NEW ENGLAND STATES.
by Elizabeth Allen
Distribution of
localities from which reports were sent in to the Eclipse Behavior Committee after the eclipse of August 31, 1932.
MAINE
NEW HAMPSHIRE
VERMONT
MASSACHUSETTS
CONNECTICUT
RHODE ISLAND
Burlington
Montpelier
Rutland
White Mts.
Green Mts.
Winnipiseogee Lake
Concord
Manchester
Lowell
Worcester
Boston
Hartford
Providence
New Haven
Newport
Martha's Vin'd
Nantucket
C. Ann
C. Cod
Cape Cod Bay
Portland
Augusta
Bangor
Moosehead Lake
Grand Lake
Kennebec R.
Penobscot R.
Androscoggin R.
Aroostook R.
Walloostook R.
R. St. John
St. Croix R.
Connecticut R.
Farmington R.
Otter R.
Winooski R.
Merrimack R.
Lake Champlain
ZONE OF TOTALITY
96%
98%
98%
96%
Scale 70 Miles to an Inch

committee also wishes to thank the fish and game commissioners of New England for their coöperation in obtaining reports of observations from their fish and game wardens.[1]

The accompanying map shows the approximate distribution of points from which observations were received in New England. Often several observations were sent in from the same general locality. The western limit was Troy, Ohio, and the eastern limit Bradford, Maine. The northern limit was Canaan, New Hampshire, and the southern limit Greenwich, Connecticut.

About 44% of the localities reporting were within the zone of complete totality, about 44% within the zone from the edge of totality to the line where it was 98% total, and about 12% in the adjoining zone where the eclipse was less then 98% total.

The total number of recorded observations used by the Committee in this survey was 498. Of these, 222 or 44.5% were observations of wild and domestic birds, 170 or 34.5% were observations of wild and domestic mammals, 65 or 11% were insect observations, 36 or 9% were reptile or fish observations, and 5 or 1% were plant observations.

The report which follows does not give us sufficient information in the case of many species of birds, mammals, and insects that were observed during the eclipse, to justify the drawing of definite conclusions about their behavior. We believe, however, that this is the first comprehensive and scientifically conducted study of the behavior of animal life during a total eclipse and that it answers many questions of general as well as of scientific interest which are not explained in the published records of previous eclipses.

INSECTS.

By William Morton Wheeler.

During the total solar eclipses of the past, most observations on animal behavior have naturally been confined to birds and mammals. We have found, however, a few records of modifications in insect behavior. During the eclipse of July 28, 1851, Arajo, at Lille Edet, Sweden, noticed that "a swarm of ants, which were busily carrying their burdens, stopped and remained motionless till the light reappeared," and Svangren, in the same locality, noticed that a "bee seemed to hasten home." During the eclipse of May 1900, Rev. A. Morford, at Ovar, Portugal, found that "ants returned from their journeys and collected around their holes, but did not enter," and Sharp, at Santa Barbara made the following note: "Bees stopped humming during totality. Hard at work immediately after, but butterflies (clouded yellows, swallowtails, etc.) did not recover equanimity for some time." Absolute stillness was noticed in crickets and ants.

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[1] We are grateful to the Bond Astronomical Club for their contribution towards the publication of this report.

Many more observations were made during the total eclipse of August 31, 1932 in New England and Ontario. They relate to a number of common insects, which in most cases cannot be specifically identified, since the observations were not made by professional entomologists. The following reports are therefore grouped under family and generic heads in taxonomic order.

COCKROACHES (*Blattidæ*).—W. J. Bielvich, Lawrence, Mass. reports that he was "informed by a lady that shortly after the total eclipse her pantry was greatly infested by cockroaches." (Probably *Ectobia germanica*).

CRICKETS (*Gryllus* sp.)—"Black crickets. With increasing darkness these were obviously more noticeable for their chirping than before the eclipse in the place where we were sitting" (Prof. Glover M. Allen, Brunswick, Me.)—"At 3.15 crickets chirped" (M. E. Almy, New Bedford, Mass.)—"Crickets became very noisy during the darker period" (E. W. Backus, Ayer, Mass.)—"During the time of totality not a sound was heard except the chirping of numerous crickets" (Vernon Bailey, Squam Lake, N. H.)—"Noted incessant chirping of crickets" (F. L. Baker, Annisquam, Mass.)—"Could only hear the noise of crickets" (H. Bowley, Dedham, Charles R., Mass.)—"Crickets began to chirp before totality, when sun was two-thirds hidden. Cricket music was evidently on for the evening as it continued" (H. B. Boyce, S. E. of Conway, N. H.)—"In the stillness of totality crickets began to chirp and they seemed to make much louder chirps than usual" (E. G. Callahan, New Braintree, Mass.)—"Heard crickets chirping throughout the eclipse" (A. A. Carter, Fryeburg, Me.)—"We could hear crickets very plainly although it may have been that we were looking for the unusual" (W. E. Chase and Mrs. H. S. Durkee)—"Crickets were singing in the yard and nearby places while it was dark" (Chas. A. Clark, E. Lynn, Mass.)—"Crickets were unusually noisy" (J. A. Cole, Epping, N. H.)—"Crickets were chirping" (K. F. Coney, Limington, Me.)—"Crickets chirped" (H. V. Dawson, Bradeford, Me.)—"We also noticed that the crickets chirped" (Mary F. Dunn, Dorchester, Mass.)—"I noticed near totality that the crickets began chirping as if night were coming on" (G. A. England, Laconia, N. H.)—"At 3.30 the chirping of crickets became so loud as to command attention (time noted when turkeys entered barn); it had not been noticed previously to this time, and it was observed that the chirping gradually diminished shortly after totality" (E. B. Hald, Denmark, Me.)—"I noticed that the crickets started singing around two o'clock and continued since that time, with the exception of extreme totality, when the air was still" (Alice E. Hall, Lancaster, N. H.)—"The crickets set up a lively chirping just as they do at nightfall" (H. C. Harrington, E. Kingston, N. H.)—"Crickets were chirping all the time" (B. N. Hodgson, Bean Hill, Belmont, N. H.)—"During the darkening process of the eclipse, I noticed how lustily the crickets sang; when the sun was bright they were still" (Mrs. M. L. Kingman, S. Hampton, N. H.)—"At about one quarter eclipse the crickets started chirping and soon there was a continual chorus lasting through the entire eclipse and some time after" (S. J. Lowe, E. branch of Westport R., Westport, Mass.)—"At 4.15 crickets began to chirp and continued for one hour" (Mr. and Mrs. F. L. Oaks, Framingham, Mass).—"At the time of totality there was a strange hush over everything—all the insects stopped their "fiddling," resuming it as soon as the light returned" (E. D. Oliver, Wellfleet, Cape Cod, Mass.)—"The crickets chirped as loud as on any summer's night" (Mrs. W. J. Plummer, West Lebanon, N. H.)—"What I noticed especially during the eclipse was the chirping of crickets as darkness came on" (Chas. W. Remick, Conway, N. H.)—"Crickets singing" (Mrs. A. Railt, Elliot, Me.)—"Crickets started their night song" (Mrs. L. Rogers, Westwood, Mass.)—"Crickets chirped" (A. A. Shurrocks, Nantucket, Mass.)—"Crickets increased their chirping" (J. A. Stenart, Somerworth, N. H.)—"Crickets were singing" (L. L. Strickland, Wells, Me.)—"Crickets began to sing" (A. H. Teague, S. Peabody, Mass.)—"The crickets began to chirp their even-song by four and apparently acted as they usually do in early evening" (G. L. Thompson, Dighton, Mass.)—"About 4 P.M. crickets began to chirp as they do at sunset" (R. E. Trask, Beverley, Mass.)—"Noticed that crickets started their chatter and later, as light appeared, they stopped" (Chas. E. Tribon, Sewer Beds, Brockton, Mass.)—"At about 4.30 the crickets began to chirp and have kept it up since"

(H. T. Wheeler, Lexington, Mass.)—"The fall crickets chirped a full chorus" (Anonymous, Warner Village, N. H.)—"At Old Orchard Beach, with the totality phase of the eclipse, myriad crickets set up their shrill calls, continuing until the sun came forth again, when they became silent" (Anonymous, newspaper clipping, Old Orchard, Me.)

KATYDIDS (*Locustidæ*). There are only three observations on these insects and only the first refers without doubt to a true Locustid. "At the darkest period of totality a small Locustid of some kind started singing near us with a thin, high-pitched "zee-ing," not very loud but more or less continuous, such as I usually have heard only in evenings. It stopped after the sun came out again." (Prof. Glover M. Allen, Brunswick, Me.)—"During the darker period the katydids remained silent" (E. W. Backus, Ayer, Mass.)—"The katydids set up their chanting which was kept up a few minutes and then turned out weakly as though they had been led into an error of which they were ashamed" (W. E. Chase and Mrs. H. S. Durkee).

GRASSHOPPERS (*Acrididæ*).—"Two grasshoppers climbed to the top of a sunflower and clung half way motionless. They made no move till after eclipse" (J. A. Stenart, Someworth, N. H.)

DRAGON-FLIES (*Odonata*).—I. R. Marshall, Reading, Mass., and G. McFarland, Atlanta, Ontario both mention dragon-flies as acting "very peculiarly" or "confused" during the eclipse, but the behavior is not more clearly described.

CICADAS (*Cicadidæ*).—"The shrilling of the locust, very noticeable before the eclipse began, ceased altogether" (B. N. Hodgson, Bean Hill, Belmont, N. H.)

BUTTERFLIES (*Diurnal Lepidoptera*).—"The butterflies were not seen" (Mrs. W. J. Plummer, West Lebanon, N. H.)—"The butterflies were slower in leaving but began to disappear and by 4.20 none was in sight" (G. L. Thompson, Dighton, Mass.)—"Butterflies disappeared but reappeared about three quarters of an hour after the eclipse" (A. A. Shurrocks, Nantucket, Mass.)

MOTHS (*Nocturnal Lepidoptera*).—"Night millers were thick" (C. M. Davis, Long Island, Casco Bay, Me.)—"I did see one moth" (W. P. Smith, Wells River, Vt.)—"Many night-flying moths appeared and flew about ten minutes" (H. T. Wheeler, Lexington, Mass.)—"Numerous moths flew about during the latter part of the eclipse" (W. M. Wheeler and T. Barbour, Beverly Farms, Mass.)

MOSQUITOS (*Culicidæ*).—"For the half hour previous to the eclipse, mosquitos were noticeably absent while we sat waiting in the warm sun, on the ledge. Towards the end of totality with the drop in temperature and the feeling of increased dampness, dozens of them came from their hiding places in the surrounding grass and started to bite. They were still about, a few minutes after the eclipse was practically over. This was the most definite reaction to light and coolness that we saw" (Prof. Glover M. Allen)—"A mosquito bit me at 3 P.M. during the semidarkness" (Vernon Bailey, Squam Lake, N. H.)—"A great many mosquitos at 4.15 P.M." (H. Bowley, Dedham, Charles R., Mass.)—"Mosquitos were noticed after the eclipse and more had been noted previously" (A. A. Carter, Fryeburg, Me.)—"The mosquitos were thick" (C. M. Davis, Casco Bay, L. I.)—"A swarm of large mosquitos appeared and pestered us terribly during the last three or four minutes before the corona appeared. They acted wildly and our stockings attested to the bites, for they drew blood and never let up" (M. E. Hartman, Newburyport, Mass.)—"Mosquitos in some places took the eclipse darkness as an excuse for coming abroad early. Mrs. George L. Moore of Wellesley reports that swarms of them appeared at her home shortly before the time of greatest darkness and disappeared again when the light returned" (newspaper clipping)—"Mosquitos began coming down from trees and out of grass and were very vicious, especially between 4.15 and 4.45 P.M." (Mr. and Mrs. F. L. Oaks, Framingham, Mass.)—"There were some mosquitos at 4.30, more and very hungry at 4.45, not so thick at 5.00 and gone at 5.30" (P. F. Quinn, Stony Brook, Conn.)—"Only time I was molested by mosquitos was two minutes during total eclipse" (S. Stockman, Salisbury, Mass.)—"At 4.15 mosquitos began to appear in considerable numbers and at 4.25 were as troublesome as at night" (G. L. Thompson, Dighton, Mass.)—"Mosquitos came out and I was bitten" (W. C. Weller, Gloucester, Mass.)—"Mosquitos flew about" (H. T. Wheeler, Lexington, Mass.)—"Mosquitos emerged from the grass and were annoying during the darker portion of the eclipse" (W. M. Wheeler and T. Barbour, Beverley Farms, Mass.).

GNATS (*Chironomidæ*).—"Gnats were in milling swarms as at twilight" (E. D. F. Jeffers, Richford, Vt.)

HOUSEFLIES (*Musca domestica*).—The reports on the behavior of houseflies during the eclipse are very meager. (F. D. Hazzard, W. Acton, Mass) "noticed great swarms of houseflies clinging to the screen door" and (G. L. Thompson, Dighton, Mass.) noticed that "the houseflies seemed to be but little affected."

Honey-bees (*Apis mellifica*).—The observations on honey bees during the eclipse are of considerable value because several of them were made by apiarists, who are well-acquainted with the normal, every-day behavior of these insects. Mr. D. T. Troyers, Jr., N. Weymouth, Mass., noticed that a swarm of perhaps two hundred bees that had been visiting a flowering bush for two days, showed signs of "apprehensiveness" about two minutes before eclipse totality, when it grew darker "they ceased their labors on the bush and flew round about. By the time the greatest degree of darkness had arrived there was not a bee to be seen. After a lapse of twenty-two minutes they again appeared." Mr. E. Kellstrand, Rockland, Mass., reports as follows: "I have fifteen colonies of bees which I watched closely. The field bees had been working heavily on goldenrod all day and everything was normal till darkness began to come on, when they came home in unusually large numbers. When it was darkest they had not all reached the entrances of their respective hives and it was then too dark for them to see their way, so they kept flying about in the air or landed in the grass, till it lighted up again. Then they found their way home and became very quiet. Some stragglers still came in from a distance. Later, after the eclipse was nearly over, they ventured out again very slowly." The following reports are similar: "I have four hives of bees. The day was a good one for them to be out gathering honey and therefore when the eclipse began bees were going out and returning at a lively rate. With the first perceptible dimming of the light there was no change in the bees' activity, but as darkness increased the outgoing bees diminished in numbers and the return batallions grew larger. When the light was almost at the dimmest point no bees were leaving the hives, but the returning individuals were pouring in by the thousands. The space above the hives was like a funnel into which bees were literally pouring from every direction. When the light began to increase there was not a bee to be seen in the air. For them evidently it was the sudden advent of night. I watched to see whether with the return of light they would go out again. Normally they go out till dusk, but in spite of the bright sunshine following the eclipse only an occasional bee ventured forth" (T. Clinton Brockway, Hingham, Mass.)—"From my point of observation it was interesting to see the honeybees stop working and the night insects start singing, all in less than twenty minutes" (T. M. Spalding, Bradford, N. H.)—"I also observed several hives of honeybees and noticed that they all hurried back to their hives" (H. F. Joray, Sharon, Conn.)—"Mrs. B. C. Green of Keene, N. H. reported that she noticed a number of bees that went away when it was darkest but came back again when it was over"—Bees working on a plant "flew around and around and finally flew away" (H. F. Chamberlain, S. Hanson, Mass.)—"The bees observed seem to have been more affected than other insects. At 3.45 they apparently were nervous and began to seek shelter. At four practically all bees had disappeared from flowers in my garden and at 4.30 none could be found on examining a large number of flowers" (G. L. Thompson, Dighton, Mass.).

The two following accounts by H. T. Wheeler, Lexington, Mass. and Joseph R. Burgess, Nantucket, Mass. give many additional details: The former writes: "During the period of the eclipse today I closely watched the behavior of eleven strong colonies of bees. They have been particularly busy on the big late honey flow from yellow goldenrod and buckwheat, and were very active at the beginning of the eclipse at about 3.30 o'clock. The temperature was 85° F. and the sky partly overcast, with the sun shining through now and then. Here at Lincoln, where these observations were made, the clouds thickened and only a short sight of the sun at 4.30, just at the height of the eclipse, was obtained. There was no direct sunlight afterward. At 4 P.M. not much change in temperature or in the activity of the bees could be noted. At 4.10 P.M. many more were coming in than were going out. At 4.20 P.M. the air was full of returning bees. Those leaving the hives flew about on erratic courses and came back. They also became excited and cross and it became dangerous to stay within forty feet of the hives. I beat off two attacks and returned to a safe distance. At 4.30, the period of greatest darkness, the fronts of the hives were covered with bees all trying to get in at once. At 4.40 a few stragglers came in—those caught in the dark a long way from home. At 4.45 there was not a bee in sight, not a sound in the apiary except the hum in the hives that is usually heard at night when the ear is held close to the hive. There was no outside activity, all having apparently arrived home. At 4.55 a few scouts came out and flew around, but as the clouds had become quite dense and the temperature had dropped to 74°—only 6 degrees above the supposed minimum at which bees work (I have, however, seen those which are hybrids, working at 55° F.)—the whole 2,750,000 of them, more or less, decided to call it a day and do house work. Probably the bees would have worked till nearly seven had the day been clear, as they usually work for sometime after sunset."

Mr. Burgess's observations on five hives were published in the Nantucket *Inquirer and Mirror,* September 10, 1932 and are here reproduced:—

"Nothing unusual was noted at first. The flight to and from the fields seemed normal. As it darkened the flight quickened and at the time of the greatest totality, the air was full of bees—a great roar of wings ensued and the entrances to the hives were blocked with bees trying to get in. Hive No. 3 appeared to have the least number. The great rush of bees was over at 4.32 in all hives except in No. 3. The others apparently had settled for the night. Guards walked back and forth at the entrances and there was no flight in the fields and little from the fields. Ordinarily the flight tapers off as sunset and night approaches. Hive No 1, which is composed of some black bees, started to drive the drones from the hive. Bees do this only after the nectar flow falls, especially in the Fall.

Hive No. 3, not in the shade, showed a steady flow of bees for five minutes after the others.

As the minutes passed and the sun grew larger, the bees appeared disturbed. Now and then one would look out, fly out a few feet and then return to the hive. A few ventured forth.

At 4.50 everything was normal again. Just the sort of flight that occurs early in the morning. Flight getting stronger continually."

Mr. Burgess offers the following as his explanation of the behavior of the bees:

"Hive No. 1 consists of hybrid bees. The queen was bought for a pure Italian, but apparently she isn't. Black bees are more nervous than the Italians and this particular hive has given me trouble by robbing the others when the clover flow stopped in July. Either the bees were upset and this started them driving out the drones or, by some sense we know nothing about, they decided that the short Fall days were coming and it was time to get rid of the drones. The latter is open to serious argument, of course.

"As to Hive No. 3. The hive itself received more light at the time of the eclipse; the light conditions in the fields where the bees were working were, as far as I know, the same. Why should the bees continue to pile in this hive five minutes or more after the flight of the others had practically stopped? Possibly the bees in that hive had been working at a greater distance, and the fact that these particular bees were in a light hive was a coincidence, I don't know."

Only two of the observers failed to notice anything peculiar in the behavior of the honeybees during the eclipse. J. A. Stenart (Somerworth, N. H.), reports that "the bees on the bamboo bush, when darkness obscured the sun, evidently did not mind, but kept on gathering honey," and S. J. Lowe (Westport, Mass.) found that "the bees continued to work all the time as though nothing out of the ordinary was going on." These observations cannot be given much weight, however.

BUMBLEBEES (*Bombus* sp.)—A single observation on a bumblebee is reported by Margaret Harwood, N. Truro, Cape Cod, Mass.: "A bumblebee flew onto the coatsleeve of one of the men who were sitting on Mr. Aldrich's veranda to observe the eclipse. The bee became lifeless during totality. Several of the men blew smoke on to it but it did not move until the sky was decidedly lighter after totality was over." The reaction to darkness and lowered temperature might be expected since bumblebees not infrequently pass the night in flowers in a quiescent condition.

WASPS (*Vespa* sp.)—Mrs. L. Rogers, Westwood, Mass. noticed that "wasps went into their nest" during the eclipse.

ANTS (*Formicidæ*).—The behavior of ants during a total eclipse might be expected to resemble that of honeybees and wasps, but the observations reported are too few to admit of a conclusion. According to G. McFarland (Atlanta, Ontario), "A number of ants of the species *Monomorium pharaonis* and *Camponotus pennsylvanicus* continued to hurry about apparently unmoved," and A. A. Carter (Fryeburg, Me.) noticed that "a rock upon which people had been seated for an hour during the early part of the eclipse was a mass of very active ants about five minutes after totality." Of course, the ants mentioned in the latter observation may have congregated on the rock because their nests had been disturbed by the movements of the spectators. F. D. Hazard, W. Acton, Mass., noticed "flying ants coming out of their homes in the soil." This was evidently the beginning of a nuptial flight, the stimulus to which was probably the fall in temperature during the eclipse, since it is well known that these flights are initiated by temperature and not by photic stimuli.

REMARKS.

So much of the behavior of insects is of the tropistic or reflex type that we should expect these organisms to respond readily to such stimuli as the rather rapid diminution of light, fall of temperature, and increase of humidity observed during a total eclipse of the sun. Nocturnal insects, like the cockroaches, crickets, moths, mosquitos, and some katydids, should exhibit their typical activities, and diurnal forms, such as the grasshoppers, meadow locustids, dragonflies, cicadas, butterflies, some gnats, houseflies, honeybees, bumblebees, wasps, and ants should suspend their activities during the period of darkness and resume them as soon as normal conditions supervene. The observations cited above fulfil these expectations.

Field observation on insect behavior is, of course, difficult during a total eclipse, because the observer is apt to be very desirous of witnessing at the same time a wonderful astronomical event, which he may never again be able to contemplate. Moreover, notes on the activities of single insects are apt to be indecisive under the most favorable conditions, and the time for repeated observation during an eclipse is quite insufficient. On the other hand, observations on insect aggregations and societies are much more satisfactory since they have at least a rudimentary statistical value. For this reason the numerous observations reported in the preceding paragraphs on the crickets, mosquitos, and honeybees are the most instructive. Nearly all the observers call attention to the chirping of crickets during the darker period of the eclipse and several mention an intensification of this activity. Perhaps, however, this is due to concentration of attention or expectation and therefore to be attributed to the unusual state of the observer. In observations undertaken during future eclipses both this and other dubious details suggested by the reports, will no doubt receive attention. Enough has been learned to show the interest of the subject and to suggest further problems and methods of greater precision in observation. Even the astronomers had to learn what to expect during a total eclipse before they could make elaborate preparations beforehand for securing accurate quantitative data. The biologist may be expected to adopt a similar course.

COLD-BLOODED VERTEBRATES.

By Clinton V. MacCoy.

A total of thirty nine observations on cold-blooded vertebrates was reported to the Boston Society of Natural History. Of these thirty six were used in making this report.

In preparing this report on behavior of these vertebrates during abnormal photoperiodic conditions it is interesting and deplorable to note how little is known of the normal actions of these animals and their ordinary behavior and response to the usual daily and seasonal photoperiodic fluctuations. Movements of fishes may be attributable to varying intensity and duration of light, food, temperature, currents, chemical or physical constitution of the water, or to breeding stimulus which may be a corollary of duration of light.

FISHES.

Fifteen observations were made on fishes by fourteen observers. Of the fifteen observations made, only seven contain the correct names of the fishes or give sufficient data to enable positive identification. This leaves eight observations made on "fish," "small fish," "small fish like minnows," "trout," and the like which are not referable to any species.

BROOK TROUT. (*Salvelinus fontinalis* (Mitchill))—It is probably generally agreed that the brook trout is sensitive to meteorological changes, but as to just how these changes affect this species has not been satisfactorily explained.

Mr. G. R. Bowman, who is probably referring to this form, reports that at Lost River, Beaver Pond, N. H., "I rose trout very early in the morning and at sunset but as the sun became obscured and dusk began to shadow the waters at the moment of eclipse I rose and hooked two trout, landing them both, one 14½ inches and one 11 inches, then the sun came out again and not another rise till dusk again."

Another report, presumably relating to this trout, telling the opposite story, is from Mr. A. J. Stobie, who reports from the path of totality in Maine:

"We had several men at the different hatcheries in this locality watching the fish and some of them were being fed at the time, just before the eclipse occurred. The fish were feeding good, but as soon as it grew dark they immediately stopped feeding and went to the bottom."

While this is the antithesis of Mr. Bowman's report, it must be realized that under hatchery conditions and with apparently regular feeding times, the fish may have developed a diurnal rhythm different from that of the normal fish in natural habitat.

GOLDFISH. (*Carrassius auratus* (Linné))—Mr. Gregg reports that at the Middlesex Fells Zoo, in Stoneham, Mass., during the eclipse, which was partial at this point, "The golden carp left the depth of the pool and started surface feeding as they do every evening." I have assumed that these "golden carp" belong to the species under which this account is given.

Meek in *The Migrations of Fish* (1916, p. 177) writes that, "the members of the carp family, as a whole, exhibit usually an alternation between relative passivity during the day and activity at night."

Mrs. J. J. Conners of Somerville, Mass., reports that the goldfish remained absolutely still.

One observation, from Mr. G. H. Fuller, of Allston, Mass., tells of two goldfish, one of the fancy, long-tailed variety, the other of ordinary form, which had lived together for many months. During the eclipse the ordinary goldfish ate off the tail of its companion and killed it. While this action may not be directly attributable to the eclipse of the sun, it is thought advisable to include it for sake of completing the records of observation on this species.

COMMON PICKEREL. (*Esox niger* Le Sueur)—From Charles River, Dedham, Mass., Mr. H. Bowley writes that, "pickerel that always jump out of water in this part of the river at dark, began jumping out during the darkness of the eclipse."

Mr. James A. Peck reports from Fitchburg, Mass., that a "half hour before eclipse the fish jumped continually . . . , and I never saw fish so ferocious, especially the pickerel."

SMALL-MOUTHED BLACK BASS. (*Micropterus dolomieu* Lacépède)—Mr. Harry M. Farr writes that, he began fishing for black bass in Littleton, N. H., just as the eclipse commenced and that the fish bit so well that he caught twelve previous to totality. They stopped biting, however, one minute before totality, and just after totality two were caught. The observer says he stopped fishing when the sun was about half clear.

From near the Winnipesaukee Post Office, Lake Winnipesaukee, N. H., where the view of the phenomenon was perfect during the entire period of totality, Mr. E. K. Robinson writes that he passed a man and his wife who had been fishing for bass from a bridge for several hours. They said that there had been no difference in the way the fish bit during the total eclipse, for they had not bitten during the entire day.

This same gentleman said he observed a most unusual spectacle while the sun was under eclipse. The visibility in the lake, which was especially calm, became unusual while the sun was under the shadow of the moon, and it was possible for him to see to the bottom of the lake for a great distance from the bridge. He said that hundreds of fishes became visible, mostly small ones like minnows, but numerous larger fish which were presumably bass. While the sun was obscured all the fishes which he observed came up very near the surface of the water. They did not, however, indicate any greater interest in the bait on the observer's hook than they had before the eclipse began. The astonishing increase in the visibility through the water and the tendency of the fishes to rise to the surface during the eclipse were two unusual features which this observer especially noted.

WHITE PERCH. (*Morone americana* (Gmelin))—Mr. Norman S. Easton reports that during the afternoon of the eclipse he was fishing for white perch on South Watuppa Lake, near Fall River, Mass. At first his luck was poor, but as the sky became darker, the perch bit more vigorously. When the shadow had passed and the sky again became clear, the fish ceased to bite, but again resumed their activity when the real evening twilight descended.

Observing at Great Lake, Belgrade Lakes, Me., Sarah S. Drake writes that as she waded through the lake two white perch came within three feet of her and swam alongside. Soon two more did the same, and then from the deeper water appeared a large one and a small one which joined the others, and when she reached the landing, the fish swam under it.

AMPHIBIANS.

Nineteen persons made as many observations on the behavior of amphibians. Five of these observations are referable to a definite species. The others can be given no more than a generic name. These reports deal only with frogs and toads, no observations on salamanders having been reported.

AMERICAN TOAD or FOWLER'S TOAD. (*Bufo americanus* Holbrook or *B. fowleri* Garman)—Three reports refer definitely to toads but it is impossible to tell whether *B. americanus* or *B. fowleri* is meant.

Of photoperiodism in *B. americanus*, Dickerson (1906, p. 80) writes: "The toad remains quietly sleeping throughout the greater part of the day, thereby keeping himself from being a nuisance and also saving himself from the danger of being stepped upon. But at sunset, or often earlier than that, he comes out from his bed under porch or shrubbery and starts on his regular tour over lawns and through gardens."

Their appearance at sunset or earlier may possibly have been made in advance of the regular hour, but with only three observations, coupled with the fact that toads are often found abroad in daytime, it is unsafe to draw conclusions regarding any abnormal behavior. However, for sake of completeness the observations may be listed.

Jeanette Norcross reports that at Brockton, Mass., throughout the eclipse several toads were busy catching insects which she describes as winged ants.

Mr. V. C. Colton writes that at North Rochester, N. H., a toad appeared close to his feet and remained there until after the eclipse was over, when it hopped away out of sight. This report probably deals with *B. americanus* as it appears to be in a region somewhat north of the usual range of *B. fowleri*.

A newspaper article apparently referring to Dover, Mass., and to which the initials 'N. H. S.' are attached says:

"When darkness shut down as the period of totality approached a large flock of toads in a home garden sprang suddenly into action, and, large and small, began hopping about in frantic search for insects and worms. This extraordinary activity attracted the eclipse observers' attention. It continued until the sun again appeared, when the toads resumed their ordinary day-time quiet."

SPRING PEEPER. (*Hyla crucifer* Wied.)—Dickerson (1906, p. 143) writes that this form calls during the daytime usually from the corner of moss or leaves. She seems to infer (1906, p. 147) that from late July even into November they may be heard calling. This form is generally known to give occasional, intermittent calls throughout the day, but becomes more vociferous as dusk approaches.

Mr. Wendell P. Smith, of Wells River, Vt., reports that "a *Hyla crucifer* called for several times during the gathering gloom, but as that is frequently done at different times of day and for no apparent reason, it seems hardly chargeable to the eclipse."

From Hingham, Mass., Claire H. Cowell writes: "The 'peepers' as we call them started and did not stop until quite a bit after the sun started out again."

Sarah S. Drake, observing at Great Lake, Belgrade Lakes, Me., says that "when the sun was a small slice the frogs were peeping in the swamp as if it were night."

TREE TOAD. (*Hyla versicolor versicolor* (Le Conte))—Dickerson (1906, p. 119) mentions that this species sings at dusk, on rainy days, or during damp weather.

From Hardwick, Mass., where the sun was at no time visible, due to heavy clouds which increased the darkness, Dorothy A. Baldwin writes that "tree toads 'purred' for fifteen minutes or so at the height of the eclipse."

An observer whose identity has been lost writes that "near totality . . . a tree toad started in to give us his nightly concert but stopped as soon as the light began to appear."

Mr. S. J. Lowe made observations at the East Branch of the Westport River, at Westport, Mass., and states: "I also noted that several tree toads started peeping just previous to the start of the eclipse, this continuing during the whole eclipse."

It is doubtful whether the last two observations refer to *H. v. versicolor* or not. They may just as probably refer to *H. crucifer*, particularly the last, which refers to the "peeping," and peeping is hardly a term to describe correctly the voice of *H. v. versicolor.*

BULLFROG. (*Rana catesbeiana* Shaw.)—Mr. W. J. Bielvich reports that five minutes after totality at Lawrence, Mass., he observed two large frogs, about 6 inches in length, sitting on the bank of the city reservoir. The caretaker, he says, informed him that they are never seen in the daytime, only at night.

VARIOUS FROGS. (*Rana* spp.)—Under this heading are eight reports referring to frogs which obviously belong to this genus, but to what species it is impossible to determine.

Mr. H. Bowley says that, although frogs are plentiful at Charles River, Dedham, Mass., he heard the sound of a frog only once in a while and could not see any at 4.15 P.M.

From Stoney Brook, Conn., Mr. P. F. Quinn states that at 3.45 P.M. frogs began to call; at 4.15 called more frequently; at 4.31 called strongly; at 5.00 decreased the frequency of calling.

At Limington, Me., Mr. K. F. Coney writes that at 2.26 E. S. T. tree frogs were singing and croaking, but absolute silence reigned at totality, crickets being the first to break the silence.

Frogs were reported croaking at Bradford, Me., Annisquam, Mass., and Conway, N. H., and in Franklin, N. H., frogs were croaking as though it were evening.

REPTILES.

Of reptiles, one turtle and two snakes are definitely named, and one observation deals with "pythons."

PYTHONS.—Mr. John T. Benson from the zoo in Nashua, N. H., reports that "45 minutes before eclipse pythons were very lively, more so than they have been at any time this summer." Pythons are generally nocturnal feeders.

NORTHERN WATER SNAKE. (*Natrix sipedon sipedon* (Linné))—Mr. W. S. Watson, reporting from Lord's Cove, Lyme, Conn., says that, "a half hour before the eclipse a thirty-inch water snake crawled onto the point of rocks, about twenty-five feet from me, and stayed there until I shot it about twenty minutes after the peak."

EASTERN GARTER SNAKE. (*Thamnophis sirtalis sirtalis* (Linné))—At Woodstock, N. H., about 45 minutes after totality the writer found a garter snake which had evidently been feeding actively during the eclipse because the stomach was so full of food as to produce a large lump in the body.

PAINTED TURTLE. (*Chrysemys picta* (Schneider))—Mr. Gregg, of the Middlesex Fells Zoo, Stoneham, Mass., writes that at 4.25 P.M. ninety-five per cent of the painted turtles left their swimming board and hunted the shelter of the pool, as they do when the sun goes down, but at 4.40 P.M. all were "back to normal" as if nothing had happened.

CONCLUSIONS.

Since the reports are few in number it is well not to draw unconditional conclusions regarding them. On the whole they represent only a meagre smattering of what might be desired should one seriously attempt to make any very definite statement concerning the reaction of such vertebrates to these light conditions. However, a good beginning has been made, as may be readily appreciated when one attempts to locate previous literature on the subject.

Had the eclipse occurred in mid-morning or at noon, results might have been more interestingly different. On the whole, observations indicate a behavior in keeping with regular crepuscular or nocturnal activities of these creatures as far as known. It is here that our embarrassment arises. We must learn more about normal reaction to photoperiodic conditions.

BIRDS.

BY LUDLOW GRISCOM.

There is very little on record regarding the behavior of birds in previous eclipses. As a matter of interest a brief historical summary is given below, prepared by Mr. Harold J. Coolidge, Jr.

Total Eclipse of 1851 in Sweden.

A report by Mr. Arajo says: "In several places birds flew against houses."

Mr. L. Svangren reported: "Immediately before totality I heard all the cocks in the neighborhood crow. A canary bird which was singing cheerfully stopped and seated himself on the highest perch in his cage for as long as the eclipse lasted. Hundreds of small birds which I had not previously seen, and which were swallows and a few sparrows, flew about like mad things, seeking trees and bushes as places of concealment as if afraid to remain in the air. A wagtail remained quiet and continued to feed its young."

Total Eclipse of 1898.

A hen was seen to roost during this eclipse in India.

Total Eclipse of May 1900 in Portugal.

W. Tait of Oporto noted: "3.17 all the cocks crew vigorously. Ring doves in a cage were cooing softly. Fowls went to roost." No special effect was noticed on the fowls, turkeys, and ducks by his wife who remained in Oporto.

Dr. Somes at Oporto reported: "Pigeons being fed were much alarmed and disturbed, stretching their necks upward to the sky as if apprehensive of some bird of prey. They recommenced eating when the sun reappeared."

Baron de Soutellino: The effect on birds was less than he expected. Fowls looked uneasy and some went to roost, yet they never became silent. Wood doves cooed all the time and other birds continued singing.

Rev. A. Morford of Portugal at Ovar: "Sparrows were twittering around their roofs just as if the evening had come, and about fifteen minutes before totality swallows were flitting as at twilight. A little later they disappeared and did not reappear until long after. Fowls in the garden kept up a perpetual uneasy crowing and cackling. They roosted near totality. Shortly after the light returned they came back and set up a triumphant crowing."

H. P. Slade, Estarreja: "A nightingale was heard."

Thanks to the trouble taken by numerous (222) correspondents in sending in their observations, there are sufficient data at hand to warrant certain generalizations as to the behavior of birds during the total eclipse of August 31, 1932. Conditions were far more ideal for observations than in the preceding eclipse, when there was some discussion of this subject in the press. The activity of numerous species of birds on a summer's afternoon yielded very different results from the meager evidence afforded by the previous eclipse, which took place in mid-winter on a bitterly cold morning shortly after sunrise.

Before, however, taking up the detailed analysis of the behavior of the various birds concerned, something should be said about the observers, and the principles governing deductions regarding the behavior of birds, or any other animals for that matter. The view is taken in this summary that definite proof of any particular bird's reaction to a total eclipse and its degree is quite impossible. The most that observation can do is to provide a strong inference that the bird's behavior, if unusual, was due to this remarkable and unusual phenomenon. It will be apparent that even this inference is not justified unless it can be shown that the behavior of the bird was not really normal for an ordinary August afternoon. In other words it must have acted in a way that it would not normally have done.

There is an additional, purely psychological difficulty on the part of the observer. It is quite apparent from the reports before me that some of the observers started with the *a priori* assumption that the birds would be disturbed or frightened by the eclipse, and anything they did was interpreted as evidence to this effect and so reported.

The observers range all the way from experienced ornithologists, students of nature, and scientists, to farmers and tourists to some point of vantage in the country. It is natural that the great majority had little or no knowledge of the birds they happened to notice. It is very creditable that most of them contented themselves with reporting what they saw, leaving deductions to some one else. I here gladly quote some pertinent observations on this phase of the subject by a correspondent.

"I observed one example of how easily a person not familiar with the habits of birds can be deceived as to the significance of their actions. Just as the darkness was most intense, a male crowned crane spread its wings and ran across the cage with head held low and wings flapping. It would be easy to say the bird was frightened or excited by the darkness. The fact is that not an hour goes by without such a demonstration on the part of one of the several cranes in the cage." (D. J. Harkins, Franklin Park Zoo). Whenever possible I quote similar comments or add them myself in the systematic list beyond.

With these preliminary remarks, we may now list the generalizations in the approximate order of their importance.

(1) The evidence is overwhelming that most birds showed some reactions of an unusual nature to totality, exhibiting behavior characteristic of fear, bewilderment, or a belief that night was approaching.

(2) No birds, however, gave any extreme signs of fear or panic. No behavior reported could be regarded as equivalent to the terror evinced by ignorant men and women during the Middle Ages.

(3) There is not a shred of evidence to warrant the belief that birds were able to sense some impending natural phenomenon, as is certainly true of violent storms, and has been claimed for earthquakes.

(4) No distinctions in behavior can be made between wild native species, domestic poultry, or caged birds.

(5) The evidence is absolutely conclusive that birds of all kinds showed practically no unusual or abnormal behavior in regions where totality was 98% or less. This is of interest, as it indicates a possible similarity between avian and human reactions. Millions of people turned out to see a total eclipse and many thousands travelled some distance to observe one, but they most certainly would not have taken this trouble for a partial eclipse.

(6) Turning now to the comparison of one group or species of bird with another, there is little evidence that one kind of bird was more affected by the eclipse than another, with the possible exception of the shore birds. In fact, the amazing contradictions in the testimony of the observers is the outstanding feature of inquiries of this kind and is at first very puzzling.

We should like to think that herring gulls all showed one type of reaction and chickens another. It is not the case. The reactions of birds to the eclipse were on the whole individual rather than specific. Some gulls and chickens thought night was coming, others did not; some showed alarm, others did not; some gulls and chickens paid no attention to the eclipse whatever. While we have no reliable criteria for gauging individual differences in birds, we know perfectly well that there are such differences, and this type of variation within one species is usually greater than the variation between two different species, if we omit from consideration such habits as are compelled by differences in structure and the nature of the food to be found or captured.

That this is reasonable can be seen by analogy again with human beings. It is possible that the people of one nation are braver than those of another nation, but this difference is a slight average, based on observing millions of individuals over centuries of time. This difference is relatively insignificant compared with the enormous gulf between the bravest and the most cowardly members of either race. With different groups of birds it is infinitely more difficult to suspect average differences of behavior and practically impossible to prove them. Let us beware, then, of rash and positive generalization about the behavior of birds. No type of speculation is more easy and alluring than the explanation or interpretation of the behavior of animals nor more replete with pitfalls for the unwary.

Captive or Caged Birds.

There are reports from two zoological gardens (1) Franklin Park, D. J. Harkins; (2) Middlesex Fells Zoo, Gregg. Neither was in the area of totality. Mr. Harkins watched the occupants of the large outdoor flying cage, and reports that all birds behaved as usual. One keeper watched the owls, but these showed no signs of activity. Mr. Gregg reports very little sign of unusual behavior among his birds, but three of nine great horned owls did become active, as if night was coming on.

Numerous reports of the behavior of canaries show the degree of individual reaction excellently. The majority went to roost, one acted as though very disturbed in addition, and another paid no perceptible attention to the eclipse at all.

Domestic Poultry.

The reports from the area of totality show overwhelmingly that nearly all kinds of domestic poultry acted in a subdued or quiet manner, the flock more or less huddled together, and in most cases went into their coops. The observers usually assumed that they went to roost, but one farmer took the precaution to check this and discovered that only one of his chickens had actually gone to roost with its head under its wing.

Chickens: As a whole these birds seemed more susceptible to the eclipse than wild native species. There are numerous reports of chickens going to roost in the area south of totality, or at least starting to do so. Roosters crowed very generally as darkness approached and receded. There are the usual individual variations. Some chickens did not go to roost; in other cases various individuals in one flock behaved differently. Two observers report that their chickens rushed for the coop at the moment of maximum darkness, after having acted in an uncertain and excited manner for some minutes.

PIGEONS: All reports show that pigeons went to roost. There is only one report of an individual pigeon remaining outside the dovecot, when its companions retired.

DUCKS: A flock of ducks at Colebrook, New Hampshire, were fed regularly at 5 P.M., returning from the lake for this purpose. They returned at 3 P.M. on August 31, departing in about fifteen minutes and returning at the proper time, two hours later.

GAME FARM SPECIES: A game farm at Wilton, New Hampshire, reports that chickens, pigeons, guinea fowl, geese, and ducks either started for their night quarters or went to roost. So did ring-necked pheasants, but golden and silver pheasants paid no attention to the eclipse at all.

I close this summary with the observations and comments of E. B. Hold at Denmark, Maine. Here a flock of turkeys started to return to the barn from the pastures at three P.M when the sun was half obscured only, so that it was no darker than if there had been a light cloud. Mr. Hold makes the very interesting suggestion that as it was so light when the flock began making for the barn, they were possibly influenced more by the sudden drop in temperature than by the very slight failure of daylight.

WILD SPECIES.

There are comparatively few reports of the smaller native landbirds, for the obvious reason that the observers were primarily concerned with the eclipse, and selected good observation posts such as the tops of bare hills, which greatly limited the possibilities. On the coast, many careful studies were made of gulls, terns, and various shorebirds, which were in great abundance, and much more active and conspicuous than the majority of land-birds inland in late August.

Mr. and Mrs. Vernon Bailey, however, sent in an excellent summary from Squam Lake, New Hampshire. They observed or heard about ten species of birds in their immediate vicinity, and while none of them displayed any unusual behavior, it was noticeable that as the eclipse progressed, there was a decrease in the chorus of birds' notes and calls, and there was silence at the period of maximum darkness. Other observers confirm this general impression of the quieting down of diurnal birds. This was associated with numerous reports of the appearance of nocturnal birds. Owls hooted, whip-poor-wills called, and flocks of night-hawks appeared.

a. *Nocturnal Birds.*

1. SCREECH OWL—1 report of a bird calling at Framingham, Massachusetts.

2. BARRED OWL—Several reports of hooting from wilder sections in New Hampshire.

3. WHIP-POOR-WILL—1 report of a bird calling at Plymouth, New Hampshire.

4. NIGHT-HAWKS—Numerous reports of flocks appearing with approaching darkness from all over northern New England. These observations must, however, be partly discounted. The Night-hawk is at the peak of its southbound migration in late August, and it is not at all unusual to see them abroad in the afternoon. One observer is careful to report that the Night-hawks were about all the rest of the afternoon, though there were three hours of daylight after the eclipse was over.

b. *Diurnal Land-birds Inland.*

5. NORTHERN FLICKER—1 report of a bird which ceased feeding on the ground, and flew into a tree until the eclipse was over (Atlanta, Ontario).

6. BLUE JAY—A flock silent and quiet during period of maximum darkness (Quincy, Massachusetts).

7. CROW—5 reports on the behavior of crows. Four of these report flocks repairing to usual roosting place, sometimes silently, sometimes cawing. One report of a single bird flying wildly about during period of maximum darkness, as though excited and afraid (Atlanta, Ontario).

8 STARLING—Several reports of flocks repairing to usual roosting place. In one case a dozen birds left flock just before totality, and flew away in the darkness, an action perhaps attributable to some uncertainty of action (Nashua, New Hampshire, A. Loveridge).

9. ROBIN—One report, same as for Flicker above.

10. RED-WINGED BLACKBIRD—Small flock ceases feeding on ground and flies up into the trees until daylight returns (Atlanta, Ontario).

11. BRONZED GRACKLE—One report, exactly as for red-wing above. Another single bird at Nantucket, Massachusetts, ceased feeding on ground and looked up into sky as light returned.

12. HOUSE SPARROW—Numerous reports of flocks repairing to usual roosting places. In one case a single female remained behind on

feeding shelf, and continued to eat throughout the eclipse, as if nothing was happening.

13. GOLDFINCH—One report of a feeding flock which behaved precisely like the red-winged blackbird above.

c. *Coastal and Marine Birds.*

14. WILSON'S PETREL—Flocks following fishing trawler began to disappear as darkness increased. Presently other flocks appeared flying higher than usual and heading east. (George's Bank, Bay State Fishing Company).

15. BLACK-CROWNED NIGHT HERON—These birds roost in the salt meadow grass or in bushes during the day, and come out to the flats to feed at sunset. There are several reports of these birds appearing. On Plum Island, Massachusetts, however, where there are literally thousands, only a very few emerged in response to the darkness of the eclipse. "Two birds were discovered on a near-by mud flat as daylight returned. They stopped feeding, stood looking about, craning their necks, and often running rapidly a few steps. They gave every appearance of being uneasy and bewildered, and finally went back to roost again" (Griscom).

16. FISH HAWK—Several birds on Martha's Vineyard reported as milling around and whistling, as though excited, during period of maximum darkness (G. E. Spofford).

17. SEMIPALMATED PLOVER—Abundant at Newburyport and Plum Island, Massachusetts, both before and after eclipse (Aylward, Babson, Griscom). Showed no reactions to eclipse whatever except to stop feeding. A similar report from Martha's Vineyard (Spofford).

18. PIPING PLOVER—No reactions to eclipse (Martha's Vineyard, Spofford).

19. BLACK-BELLIED PLOVER—No reactions to eclipse at Plum Island, Massachusetts (Aylward, Babson, Griscom) or at Martha's Vineyard (Spofford).

20. DOWITCHER—Common on Plum Island meadows before eclipse. Flew off at approach of darkness and very few found in the region after the eclipse (Griscom).

21. LESSER YELLOW-LEGS—Abundant on the Plum Island meadows just before eclipse. At totality flew about calling loudly and the great majority left the region for good (Aylward, Babson, Griscom). On Martha's Vineyard, where the eclipse was not total, behavior entirely normal (Spofford).

22. WILLET—One bird under direct observation on Plum Island flew around restlessly, calling incessantly, but remained on the same mud flats (Griscom).

23. PECTORAL SANDPIPER—None under direct observation during eclipse, but common in the Plum Island meadows before the eclipse. Practically none to be found after the eclipse (Aylward, Babson, Griscom).

24. LEAST SANDPIPER—Common on Plum Island meadows before eclipse. For further comment see next species.

25. SEMIPALMATED SANDPIPER—Innumerable multitudes on Plum Island meadows before eclipse. As darkness approached, they rose up in great flocks to a much greater height than usual, and after whirling about in the darkness they disappeared. The entire area was almost devoid of these birds after the eclipse. The great Joppa Flats were fully exposed, as low tide prevailed during and after the eclipse, and they should have been covered with birds, but they were almost devoid of them (Aylward, Babson, Griscom). At Martha's Vineyard (no totality) these shore birds behaved normally (Spofford).

26. HERRING GULL—The reports of herring gulls are so numerous and the data so excellent that some discussion is well worthwhile. This species gives the best illustration available of the absolute necessity of being thoroughly acquainted with its habits in each special locality. On the coast of Maine and New Hampshire there are numerous rocky islets where the gulls breed, and it is their custom to return each evening from the mainland to roost. This is also true off the coast of Cape Ann, Massachusetts, but does not apply to Newburyport Bay or most of Cape Cod, where the bird spends the night either on the marshes or in some sheltered cove, estuary, or pond. In either case, it will be apparent that the exact roosting place must be definitely known before a flight of gulls during the eclipse could be presumed to be for this purpose, due to premature darkness.

In addition to these considerations, however, there are at least two other daily movements of the gulls north of Cape Cod, due to the relatively high tides. At high tide the gulls cease feeding and repair to various roosting places, which may or may not be the same as the night roosting places. On the approach of low tide there is a flight away from these places to feeding grounds exposed by the receding tides. It so happens that on August 31 the tide was *falling* during the eclipse, and some at least of the movement of gulls reported was due to their desire for food being stronger than their alleged surprise at the arrival of premature darkness. In fact, the failure of the gulls to leave some jetty and repair to a recently exposed mud flat would constitute a definite eclipse reaction.

Another general habit of the herring gulls must also be given consideration. On pleasant days with a clear sky and a gentle breeze, gulls, when resting at high tide or not feeding, are much given to suddenly starting up in the air in flocks, and after some soaring aloft with more or less screaming they alight again. This action was frequently reported as an eclipse reaction. Now it may well have been an eclipse reaction, but it is equally certain that some gulls at least would have done this on a normal afternoon.

The reports show very definitely that there must have been some tendency on the part of the gulls to repair to their night roosting grounds, even when full allowance is made for the considerations mentioned above. On the other hand, from every station the reports show that only a part of the gulls present were affected, some apparently paying no further attention to the eclipse than to remain quiet, often looking constantly towards the sun.

Passing now to specific instances, the most interesting report received was from Mr. W. W. Ballard, who made special efforts to be landed on Duck Island, ten miles off Portsmouth, New Hampshire, where the gulls breed and congregate at night in great numbers. A confederate was stationed in Portsmouth Harbor to see if any gulls departed. The results at both stations were negative. No birds were seen to leave the Harbor, and no birds arrived at Duck Island, perhaps, as Mr. Ballard pertinently suggests, because the darkness did not last long enough for them to reach the Island, even if any had left the mainland. On the Island a small percentage of those present, all juveniles, tucked their heads under their wings. "At the moment of totality every gull on the Island, nearly, went screaming into the air . . . and flew aimlessly about as long as the sun was hidden."

Independent observation by three different people on Plum Island, Massachusetts, yielded slightly contradictory results. Two were stationed on the edge of the "Basin" where the gulls congregate at high tide, departing at low tide for the exposed flats in the harbor. When the eclipse was about 75% total, the gulls seemed to become mildly excited and finally all but six left for the harbor (Aylward and Babson).

The other observer (Griscom) was stationed near a breakwater, on which about 100 gulls were roosting at high tide just before the eclipse commenced Normally, they should have flown to the flats to feed, but they did not do so until the eclipse was practically over. A few birds did fly to the flats, but as darkness approached made no attempt to feed. As totality approached, the tide had fallen sufficiently to make it possible to walk out across the mud flats to the breakwater. One group of fifty remained huddled on the breakwater in perfect silence, and during the sixty-five seconds of totality permitted an approach within fifty feet, which so wary a bird would not have tolerated in the usual darkness of night. All three observers, however, agree that on the whole, the gulls showed distinctly less reaction than the terns and most of the shore birds.

At Kennebunk, Maine, Howard Cleaves noted some standing on nearby rocks, which remained where they were during totality, merely engaging in slightly increased vocal activity. A compact flock of fifty were, however, observed flying silently towards the outer reefs at a considerable height. It could not be determined whether they got there or whether they turned back with returning light. Mr. Spofford on Martha's Vineyard in Massachusetts reports a similar division of activity. About half the gulls under his observation remained where they were, while the others started for their roosting grounds on Muskeget Island, but were seen to return with returning light after they had gone about half a mile.

27. ROSEATE TERN—Small numbers observed at Plum Island with common terns. Actions exactly the same (Griscom).

28. COMMON TERN—At Kennebunk, Maine, about two hundred terns on the rock reefs did not fly away, but there seemed to be an increase of vocal activity during totality (Howard Cleaves).

On Plum Island, Massachusetts, the habits of the terns are the opposite of the gulls. They feed in the harbor chiefly at high tide, roosting on bars and mud flats at low tide. They were the first birds to react to the approaching darkness. While a few remained roosting on the ground, the great majority rose in the air in flocks, dashing about in an erratic manner, and some disappeared to the east (Aylward, Babson, Griscom). The terns on Martha's Vineyard acted in a similar manner (Spofford).

MAMMALS.

By Glover M. Allen and Harold J. Coolidge, Jr.

Concerning the behavior of mammals in the path of the eclipse during the period of partial darkness, some one hundred and seventy observations were sent in, relating to twenty or more species, excluding those in "zoos." A brief summary of these follows, from which it will be seen that, except in the case of bats, for which all the evidence is necessarily of a positive nature, there is a good deal of conflicting testimony, as one might perhaps expect. In those species where the number of reports is great enough to be significant, it appears that some seemed affected rather definitely, though not uniformly, as cattle, sheep, and gray squirrels. With others the effect is less clear or negative. Mammals penned in zoological gardens reacted little, if at all, corroborating the usual impression which most species give—of having lost much of their interest in external conditions. In the case of dogs and cats, that are closely associated with man as his companions, it may be that they sensed his air of expectancy and responded to that rather than to the actual conditions of the eclipse. It is true, also, that individuals of both species are sometimes much frightened by thunder storms and may have felt apprehension at the darkening sky. One must expect, too, a range of differences in individual behavior within a given species. It should further be kept in mind that most observers have made few critical notes on the behavior of the species reported at times other than during the eclipse for comparison with behavior then.

Bat (*species ?*)—Two were seen at North Sebago, Maine, and one at Hill, New Hampshire, flying about during the eclipse, both places being within the totality belt; also one each at Providence, Rhode Island, and Boston, Massachusetts, localities in the 98–100% area.

No specific identification is possible, but some at least were doubtless the Big Brown Bat (*Eptesicus fuscus*), an early flier and often a city dweller.

The appearance of bats is recorded in the case of previous solar eclipses, for in 1706 Todd records "bewildered bats" and in the total eclipse of May 1900, Mr. Tait in Oporto notes "a bat was seen flying about during totality." During the same eclipse bats appeared in another place.

In the present survey the result of bat observation is positive.

Domestic Dog (*Canis familiaris*)—No less than twenty-two of the notes concern dogs and indicate differences of behavior in accord perhaps with the individual temperament or surroundings. Of fifty dogs at the Animal Rescue League, Boston (98-100% area), it was thought that they seemed quieter than usual. In five other cases no unusual action was observed. At South Peabody, Massachusetts, dogs "turned in" as they do at night but got up and barked with excitement when the eclipse was over. At Attleboro Falls, Massachusetts, a dog showed great nervousness and crouched near its master. At Kennebunk, Maine, a dog seemed scared and stayed at its mistress's heels. At Brockton, Massachusetts, dogs yelped just after totality, and at Salisbury, New Hampshire, one barked during totality. A dog at Stony Brook, Connecticut, became uneasy and hid under a couch and at New Braintree one barked and showed excitement. Another at Washington, New Hampshire, a Chow pup, ran frightened under a shed and could not be coaxed out. At Conway, New Hampshire (totality area), one became scared and whimpered, while an Irish terrier at York Village, Maine, seemed much frightened and whimpered.

In general, then, it appears that while in about seven cases, dogs seemed to pay no attention to the darkening conditions, in about a dozen instances distinct excitement was noted, amounting in a half dozen or more to obvious fright. Doubtless in some instances, the intelligent animals sensed something unusual in the behavior of their masters, while probably others—as obviously in at least one case—reacted as if a thunderstorm were imminent and became frightened, whimpered, or tried to hide away.

Result: negative in about a third the cases reported; positive, perhaps either from excitement or fear, in slightly over half.

Records of previous eclipses are three at Lille Edet in Sweden in 1851.

"A half starved dog who was devouring some food dropped it from his mouth when the darkness came." In another place not far off two dogs showed no alarm and ate greedily of food given them just at totality. Finally two other dogs lay still during the eclipse but refused meat that was offered them.

Red Fox (*Vulpes fulva*)—Five observations concern both wild and captive individuals. Only one is of much value. At Randolph, New Hampshire, one barked during totality, a rather unusual day habit. A wild one was seen at Stony Brook, Connecticut, "sliding by," but foxes are often abroad at this time of day. At a Hinsdale, New Hampshire, fox farm an early emergence was noted.

Result: On the whole negative or doubtful.

MINK (*Mustela vison mink*)—One at Fitchburg, Massachusetts, in the 98–100% belt appeared; actions normal. They are often seen by day under usual conditions.

Result: Negative.

SKUNK (*Mephitis putida*)—A single observation is reported: On Cape Cod in the totality area, as it grew darker, skunks came out and started "rooting" in the lawn but hurried to their burrows with the return of full light, as if directly in response to darkness and light.

Result: Apparently positive.

RACCOON (*Procyon lotor*)—Two observations. A captive one at Suncook, New Hampshire (totality area), slept as at night though usually lively; others at East Westmoreland (98–100% area) behaved as they usually did.

Result: Negative or doubtful.

CAT (*Felis ocreata domestica*)—Thirteen notes on cats and kittens come about half (six) from the totality area, and the rest (seven) from the 98–100% area. In general no very obvious reaction appears that seems directly attributable to the eclipse. Some slept through it, or played as usual; in three instances cats seemed restless, one that had been resting under a lilac bush crawled out. Most of them showed no significant behavior. In one case, however, a Maltese at York Beach, Maine, is said to have "meowed" as twilight came on, gave a "shriek" as the corona appeared and rushed up a post, watching the sun all the time.

Result: Chiefly negative; one case of apparent fright.

In the records of the eclipse of 1851 in Sweden "a cat belonging to our neighbor ran to our maidservant and showed uneasiness by mewing."

HARBOR SEAL (*Phoca vitulina*)—A group of fifty on or near the rocks at Kennebunk, Maine, was unaffected.

Result: Negative.

COTTONTAIL RABBITS (*Sylvilagus*)—A few notes on cottontails relate their coming out to feed, as on Penikese Island (98–100% totality) and at Northfield, Connecticut (96–98% totality). However, since these animals are often abroad by day and especially in the latter part of the afternoon, these reports are of doubtful significance.

Result: Negative.

Tame "rabbits" (*Oryctolagus cuniculus*) in two reports were unaffected.

NORTHERN GRAY SQUIRREL (*Sciurus carolinensis leucotis*)—In three instances out of the eight reported, a possible effect was seen where squirrels (two cases) left the feeding boxes during totality and later returned or (one case) retired to their boxes and later emerged. In a fourth instance, one cutting off acorns at Squam Lake, New Hampshire, betook itself to the woods until the eclipse was over. Again, at Wells, Maine (totality area), two squirrels ceased "playing" and took to the woods without returning.

At Pachaug Pond, Connecticut (96–98% totality area) no unusual behavior was noticed.

Result: Probably a positive reaction, in line with the habit of this species of retiring promptly to its retreat at nightfall.

Scattering observations on red squirrels, flying squirrels, and chipmunks are negative or inconclusive.

WOODCHUCK (*Marmota monax*)—One reported from Watertown, Connecticut, is of no significance as they are often to be seen in the latter part of the day.

Result: Negative.

MUSKRAT (*Ondatra zibethica*)—Three were seen during the eclipse—two at Fitchburg, Massachusetts, and one at Stony Brook, Connecticut (96–98% totality area). Since they are abroad occasionally at any hour of the day, there is no special significance to the observations.

Result: Negative.

GUINEA-PIG (*Cavia porcella*)—One at Somerville, Massachusetts, is said to have gone into its house and stayed there as if frightened. The single instance is, however, inconclusive.

Result: Doubtful.

BEAVER (*Castor canadensis*)—Captive beaver were reported on in two instances, both in southern New Hampshire. Two at Nashua were very active during the eclipse, but their usual activities are not related. At Squam Lake an occupied house was watched and none came out.

Result: Inconclusive.

VIRGINIA DEER (*Odocoileus virginianus borealis*)—Six notes on deer were received. At Stony Brook, Connecticut, two does came out to drink at the edge of the river; single deer were sighted at Keene and Lisbon, New Hampshire. These three cases seem to have no unusual feature. Three others, however, seemed to indicate a little more. At Randolph, New Hampshire, a captive deer appeared restless and thrice got up and lay down again. At Bradford, New

Hampshire, four deer fed out in the open as at twilight, but as the light returned, seemed slightly bewildered and more alert. At the Poquannsk Game Farm, Connecticut, the deer, as it grew dark, got to their feet, bunched under the apple trees, and started feeding. With the returning light, they wandered apart and presently lay down again.

Result: Probably positive, at least to some degree, when as in the last three cases, the growing darkness seemed correlated with activity and feeding.

WAPITI (*Cervus canadensis*)—One in semicaptivity at Bradford, New Hampshire, remained quietly in the clump of spruces where it was lying at rest.

Result: Negative.

RHESUS MONKEYS (*Macaca mulatta*)—Three reports of captive Rhesus monkeys agree in relating what seem positive reactions. At Nashua, New Hampshire, and at Bedford, Massachusetts (98–100% totality area), they huddled together as they usually do at evening, and at Hamilton Park, Connecticut, they climbed up into their house as at nightfall.

Result: An apparently positive reaction.

In the records of the total eclipse of May 1900 in Oporto a Dr. Barbora reports that he "saw monkeys go to boxes where they slept."

DOMESTIC GOAT (*Capra hircus*)—One observation only was quite negative—concerning a goat at Hingham, Massachusetts, that lay down in a field and continued to chew its cud contentedly.

Result: Negative.

In the eclipse of May 1900 at Oporto Mr. Slade reports that "a goat showed a total want of appreciation."

DOMESTIC SHEEP (*Ovis aries*)—Seven observations of sheep, all but one in New Hampshire and in the area of totality, showed notable differences of behavior. At Alstead, Lisbon, and Franklin, New Hampshire, as well as in the case of a large flock of five hundred and seventy at Center Sandwich, New Hampshire, they continued to feed undisturbed by the eclipse. In the three remaining cases there seemed to be a distinct response, similar to their evening behavior. At Lisbon Falls, Maine (totality area) a flock that was grazing peacefully became disturbed as darkness came on, and at exact totality the entire flock stampeded toward the barn; a flock at Conway, New Hamsphire, also came in to their evening pens, bleating. In a third instance at Milan, New Hampshire, all the sheep huddled in a bunch as they were accustomed to do for the night, but seemed in no way excited. Possibly the varying behavior may bave been in part a result of differences in habit of the various groups, some being accustomed to return to shelter at evening, others used to remaining in pasture. Again the response of one or two individuals in a group may have affected the actions of all as in "stampeding" for the barn.

Result: Positive in less than half the cases, inducing flocks to react as at evening; negative in the other cases.

In the eclipse of July 1851 in Sweden a flock of sheep was reported bleating during the whole period.

DOMESTIC CATTLE (*Bos taurus*)—Some seventy-two observations on the effect of the eclipse on the activities of cattle were received, of which 39 are from within the area of totality. Of these 39, only ten are negative. It is interesting, however, that even in the center of the totality area, differences in reaction were seen. Thus at Conway and North Conway, New Hampshire, in three cases, cows seemed quite unconcerned. In 29 of the 39 cases, however, there was a quite definite response to the oncoming of darkness, in most instances a starting in the direction of the barn, a feeding toward the barn, or arriving at the bars of the pasture or barnyard ahead of the usual milking time. In the area of 98 to 100% totality the reaction was somewhat similar, but in the area of 96 to 98% the reaction was in most cases negative.

Result: Positive in about two-thirds of the cases. Thus, by way of summary, of 72 observations, no less than 43 may be classed as positive, 21 negative, 8 doubtful. The preponderance of evidence seems to indicate that coming home to be milked and housed for the night is in part at least a reaction to lessening daylight.

In the eclipse of 1851 in Sweden during totality a herd of oxen collected themselves into a circle and stood with horns facing outward. Also cows which were lying down in a meadow at the beginning of the eclipse continued there while totality lasted, when they got up and went to the gate to go home.

HORSE (*Equus caballus*)—Of the eight observations sent in on horses in pastures, one is without the 96% area and is quite negative. In the areas of 96% to near totality, three other observations are equally negative, no reaction being noticed. Four notes are from within the area of totality, namely, Tilton, New Hampshire—kept on feeding in the pasture; Canaan, New Hampshire—no change observed; Squam Lake, New Hampshire,—horses grazed up to the corner near the barn; Exeter, New Hampshire—horses gathered, neighing, at the pasture gate.

Result: In only one case, the last, did there seem to be any response similar to that of the evening return to the barn. In the remaining seven, the results seemed quite negative. No clue to any supposed difference is hinted at, although, again, individual pecularities of habit may account for the actions observed.

In the 1851 eclipse in Sweden two references to horses showed them to be unaffected.

Animals in Captivity.

Reports in considerable detail were sent in from the following zoos or collections of animals:

Benson's Animal Farm at Nashua, New Hampshire; Franklin Park Zoo, Boston, Massachusetts; Middlesex Fells Zoo, Boston, Massachusetts; Bedford Zoo, Bedford, Massachusetts; and Hamilton Park Zoo, Connecticut.

In each case there was no behavior that could be interpreted as a direct result of the eclipse, except that of the Rhesus monkeys already referred to. The following animals were those on whose behavior reports were received by the Committee:

Elephants, lions, leopards, tigers, pumas, jaguars, lynx, wolves, coyotes, foxes, hyenas, African and Indian antelopes, bison, yak, musk-oxen, deer (many species), wapiti, zebras, camels, llama, bears, Rhesus monkeys, baboons, mandrills, and chimpanzees.

Summary.

By way of summary, the observations on ten of the twenty-one species seem quite negative or at least inconclusive, namely in the case of red fox, mink, raccoon, harbor seal, cottontail rabbit, woodchuck, muskrat, beaver, wapiti, goat. The evidence in the case of cats and horses is likewise practically negative, with one or two individual instances in which fright or restlessness seemed to be betrayed. Excluding the single instance of a guinea-pig that retreated to its shelter, as being inconclusive, there then remain eight species that seem to have been definitely affected, though in varying degree, by the early darkening of the sun's light. These are: dog, bat, skunk, gray squirrel, Rhesus monkey, Virginia deer, domestic sheep, and cows. It is interesting to find that in the dog, reactions were noted in about one-half the instances, and were expressed either as excitement or fright. As before suggested, the atmosphere of excitement may have been imparted by their human companions or possibly there was actual apprehension of an approaching storm indicated in a few cases. All the remaining seven species behaved as they would normally have done at the approach of night. The bats left their diurnal shelter to feed, as did also the skunks and deer. The gray squirrels and Rhesus monkeys, which are strictly day-living mammals, seemed on the other hand, to prepare for the night's rest, and retired for the time in a rather definite way. The sheep were less uniformly affected, for in only about half the cases did they seem to huddle together in the pasture or approach their barns as if for the night. Cows showed a definite reaction in about two-thirds of the cases reported, by coming to the pasture bars or their barnyards well ahead of their usual hour for milking. In the case, then, of the seven mammals last mentioned, the behavior seemed to be significant of a definite reaction to the gradual lessening of daylight simulating the oncoming of night.

Among the mammal observations, with the possible exception of excitement and fright among the dogs, none of the behavior which was recorded was in any way abnormal in the response to the sudden darkening caused by the eclipse. Many people have reported a personal feeling of sickness or fright during totality and shown it in their behavior. In the total eclipse of 1560 and 1567 "women screamed and fainted." In 1900 "a country woman was seen on her knees praying aloud and seizing handfuls of earth which she put in her mouth."

The survey of mammal behavior has shown no demonstration of extreme nervous or mental disturbance such as that recorded of *Homo sapiens.*

APPENDIX.

FLOWERS.

Unfortunately, very few observations were sent in to the Eclipse Committee describing the effect that the darkness or sudden change of temperature had on plants. There is no reason why many crepuscular species should not have shown the effect. The only reports to quote are those of M. J. Cook of Melrose, Massachusetts, which were as follows:

"The morning glories began to close at three-fifteen."

"The portulacas began to close at three-twenty-five."

At Warner Village, New Hampshire, some devil's paint-brush closed as for the night.

In the records of previous eclipses we find the following brief references:

Total eclipse of the sun—1706: Some flowers closed.

Eclipse of 1851—July 28: Some flowers closed.

L. Svangren—Lille Edet: Night violet which shortly before the beginning of the eclipse had little of its agreeable scent, smelt strongly during the totality.

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MEASUREMENTS OF CERTAIN ELECTRICAL RESISTANCES, COMPRESSIBILITIES, AND THERMAL EXPANSIONS TO 20000 kg/cm^2.

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Investigations on Light and Heat made and published with aid from the Rumford Fund.

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Received December 14, 1934. Presented December 12, 1934.

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INTRODUCTION.

A number of the phenomena which have presented themselves in a rather extensive survey of the properties of matter up to 12000 kg/cm^2 have proved to have features of sufficient significance and interest to justify the serious attempt to extend materially the pressure range. In this paper measurements are presented of such phenomena up to 20000 kg/cm^2. The electrical resistances of black phosphorus and of tellurium are studied; both of these substances had been found to have an abnormally high decrease of resistance with increasing pressure.[1] It was of interest to find whether the resistance of these materials could be forced by sufficiently increasing pressure to approach the resistance of the true metals. An investigation of other semi-conductors suggests itself in view of recent advances in our theoretical understanding of the nature of the mechanism of conduction; it would appear that in general there is some ground for the expectation that at least some semi-conductors can be forced into something like the metallic state by very high pressures, and that therefore a systematic investigation of such substances to the highest attainable pressures should be of interest. There are very few measurements on such substances over the lower pressure range, so that the grounds do not exist for selecting those substances which most probably will show significant high pressure effects. Furthermore, the difficulty of the investigation is increased by the fact that not many semi-conductors can be obtained in a geometrical form suitable for the measurements. The only course is, therefore, the empirical one of trying all the feasible semi-conductors. A beginning of such an exploration is presented here in measurements on CuS_2, which is easy to obtain in massive form. Finally, measurements have been made on the volume as a function of pressure and temperature of the three alkali metals, lithium, sodium, and potassium. In the last few years theoretical understanding of the metallic state has advanced sufficiently to permit a calculation of the compressibility with some success, so that a knowledge of the behavior of these especially simple metals is desirable over as great a range of pressure as possible. For some time it has, furthermore, been evident that a knowledge of the thermal expansion also of these metals would be useful, but such determinations have offered the greatest experimental difficulties, and hitherto I have not succeeded in making any good measurements for these substances, even in the lower pressure range. The primary purpose of the present measurements was to yield reliable values for the thermal expansion, and now after many attempts I believe that I have obtained values which give the essential broad features of the behavior of thermal expansion up to 20000, although the accuracy is not greater than a few per cent, and there are finer details which it would have been desirable to establish.

In comparing the present compressibility measurements over the wider pressure range with those previously made, a serious error was uncovered in my early published values for compressibility.[2] The correction for the second order effect in converting linear into volume compressibility was applied with the wrong sign in nearly all the measurements published through 1923. The compressibility at low pressures is unaffected by this error, but the volume changes at the maximum pressure were too large by a fractional amount equal to twice the change of linear dimensions themselves. The error is thus largest for the most compressible materials and for the highest pressures; at 12000 kg/cm^2 the error varies from 1 per cent for iron to 14 per cent for potassium. The corrected values are to be given in detail in another paper.

APPARATUS AND TECHNIQUE.

A number of modifications were necessary in the apparatus and technique. In the first place, a hydrostatic press of larger capacity for producing the pressure was necessary. The new press was of about twice the capacity of the old one, the diameter of the piston being 3.5 inches, against 2.5, yielding, with a maximum working pressure of 15000 lb/in^2 on the 3.5 inch piston, a total force of about 140000 lb. This could be concentrated on a high pressure piston usually about 0.5 inches in diameter, thus allowing a maximum pressure in the high pressure cylinder of the order of 50000 kg/cm^2, making no allowance for friction.

Formerly the high pressure part of the apparatus consisted of three parts: a cylinder in which pressure was produced and in which was situated the manganin pressure gauge, a connecting pipe, and a cylinder containing the particular specimen under measurement. The apparatus now consisted of a single cylinder, turned with a shoulder on the upper end, by which it was retained in the lower head of the press, the bulk of the cylinder projecting beyond the press as indicated in Figure 1. The temperature bath was brought up around the cylinder, the liquid in the bath standing nearly to the top of the cylinder and covering the lower head of the press and the lower ends of the tie rods. The cylinder, except for a by-pass at the upper end by which it was charged as usual to an initial pressure of 2000 or

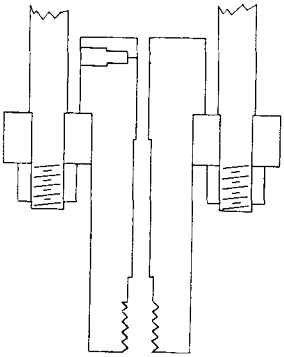

FIGURE 1. Section of the high pressure cylinder mounted in the lower end of the press.

3000 kg/cm^2, was pierced with a single longitudinal hole. This is a departure, made necessary by the demand for maximum strength, from the previous design, in which the manganin gauge was let in through a hole at the side. The leads for the manganin gauge were now brought in at the bottom, along with the leads necessary for the potentiometer measurements, as will be described later.

An alloy steel was used for the cylinder, capable of giving higher physical properties than that which had been formerly used. Formerly a Cr-Va steel of approximately the analysis SAE 6150 was used, giving a maximum tensile strength of 225,000 lb/in^2. This was now replaced by a steel made by the Carpenter Steel Co. under the designation "S-M," and analyzing approximately 0.60% C, 0.75% Mn, and 1.90% Si. It may be heat treated to give a tensile strength as high as 320,000 lb/in^2, and has the remarkable property of showing considerable elongation even when treated to give as high a tensile figure as this. For the high pressure cylinder this steel was quenched into water from a temperature of 900° C, and then drawn at a temperature of 400° C, when it showed a Rockwell C hardness of 48, just soft enough to permit enlarging the hole with a reamer after the usual preliminary stretching. The stretching was usually done with lead, as before. The maximum pressure of the preliminary treatment was about 30000 kg/cm^2 for a cylinder to be used regularly to 20000, and the stretch of the interior under this preliminary treatment might be as much as 0.06 inch on an initial internal diameter of 0.44 inches and external diameter of 3.8 inches. After the preliminary stretching one or two of the cylinders were subjected to a low temperature anneal, without any very distinct evidence of improvement. The life of the cylinder was capricious, cylinders having broken after only a few hours use at 20000, while one or two have had a life of about 30 hours total exposure to the extreme pressure of 20000. Rupture may occur at pressures materially less than the maximum previous exposure. In all, five cylinders were used in the measurements to be described here.

The pistons were made of a special chrome ball bearing steel, left glass hard; and seldom gave trouble. Because of the violence of the failure of glass hard steel under compressive load, however, it is necessary to use adequate protecting shields in case of failure of the piston. The high pressure piston was packed with a plug of the same mushroom design, using the principle of the unsupported area, as has been used previously.[3] Failure of these packing plugs by pinching-off of the unsupported stem was at first fairly frequent, but has been minimized by the use of a steel made especially for cold chisels, possessing great toughness combined with high strength, by avoiding reentrant sharp angles, and by avoiding the use of soft solder in attaching the soft packing washers of brass or copper to the mushroom. This last seems to be an important point; apparently tin ultimately gets forced by high pressure into the pores of the steel, the process being assisted by the natural chemical affinity of tin and steel, and failure ultimately occurs by the analogue of the amalgamation failure previously found with mercury at a pressure of a few thousand kilograms.

The packing of the pistons is becoming one of the more serious problems in considerably extending the pressure range, and some simple device which will avoid the pinching off effect is desirable. I have had no luck with the simple solid rubber plug used by Poulter and by Imperial Chemical Industries Limited. This may be suitable if the transmitting liquid is highly viscous, but if the liquid is of low viscosity I have found that leak invariably occurs in the neighborhood of 10000 kg/cm^2. In the present experiments it was necessary to use a liquid of the lowest possible freezing point and lowest possible viscosity; iso-pentane was the liquid so employed. It has a high initial compressibility, but this disadvantage was obviated by the initial charging through the by-pass.

The details of the method of bringing in electrically insulated leads had to be modified. The leads were now all brought through a single plug at the bottom of the cylinder; there were four such insulated leads, one for the manganin gauge coil, and three for leads to the potentiometer by which the resistance of the specimen was measured, the fourth potentiometer lead and the other lead to the gauge coil being grounded to the cylinder. The insulated leads were made of piano wire 0.010 inches in diameter. The mica washers previously used were now replaced with Solenhofen limestone, as has been used at the Geophysical Laboratory in Washington, for greater strength; furthermore the limestone cylinder was embedded in a brass sleeve which flowed sufficiently around it to prevent cracking by concentration of stress at the unavoidable local geometrical irregularities. The rubber washers by which the liquid was prevented from leaking around the stem were now replaced by a double washer, artificial rubber (Duprene) at the end next the liquid, and soft natural rubber below it. The Duprene is not attacked by iso-pentane, but is not quite soft enough to give complete freedom from leak at the lower pressures, which is ensured by a thin layer of natural rubber. The soft packing on the mushroom plug has also been made of Duprene in these experiments with advantage, there being a marked improvement in the wearing qualities.

The general design of the plug carrying the insulated leads was radically altered; the proportions of the holes carrying the packing around the piano wire stems were so changed as to give a considerably greater ratio of length to diameter, and the plug itself was not made integral, as before, with the screw by which it was retained in the cylinder, but was a separate piece. This permitted the plug to be made much shorter, a change which greatly facilitated construction by avoiding the long accurately placed holes of small diameter demanded by the former method of construction.

The measurements of electrical resistance described in the following were made by the same potentiometer method that has been used in much of my previous work, and no further description is necessary.

The changes of dimensions of the alkali metals were measured in a piezometer of the same general design as that formerly used, but differing in detail. Attached to the specimen is a fine wire of high specific resistance, which moves over a contact fixed to the envelope containing the specimen as the dimensions of the specimen change under changes of pressure and temperature. Potentiometer measurements of the resistance of the wire between a point fixed to it and the sliding contact permit a calculation of the amount of motion, and thus the changes of dimensions of the specimen relative to the envelope. The distortion of the envelope is assumed to be known from previous measurements. Actual measurements of the compressibility and thermal expansion of steel have been made only up to 12000 kg; the results assumed here up to 20000 were obtained by extrapolating with the same second degree formulas which were adequate to represent the results over the 12000 kg range. This procedure seems safe enough in view of the small departure from linearity in the range up to 12000, and the smallness of the volume changes in steel compared with the alkali metals.

One very serious source of difficulty was permanent changes in the dimensions of the specimens, the transmitting medium becoming viscous enough under pressure to deform permanently metals as soft as these alkalies. The difficulty was minimized by changing the pressure very slowly, and by suitably varying the dimensions of the specimens. The specimen of lithium, which is mechanically the hardest of the three, was 5.8 cm long and 6.0 mm in diameter; the sodium intermediate in softness, was 2.5 cm long and 8.7 mm in diameter, and the potassium, softest of the three, 1.27 cm long, and 8.7 mm in diameter. The compressibility increases from lithium to sodium to potassium, so that in spite of the shorter length of the potassium, the relative change of dimensions of all three was roughly the same.

From the point of view of simplicity of manipulation it would have been very much to be preferred to obtain the thermal expansion as a function of pressure from the difference of isotherms, each described over the entire pressure range. Measurements were desired at five temperatures, 0°, 30°, 52.5°, 75°, and 95°, so that this would have involved describing five isotherms to 20000 with practically perfect recovery of the zero, if thermal expansions were to be obtained by difference. In spite of many attempts, such perfection was not obtained. It was not difficult to describe a single isotherm with sufficiently small permanent distortion to give the isothermal change of volume with small error, but successive isotherms always involved sufficient permanent distortion to introduce large percentage errors into the relatively small differential thermal expansions. Two different procedures were therefore finally adopted for getting compressibility and thermal expansion. The compression at 0° C was first determined by describing an isotherm over the entire pressure range, up and back, at this temperature. There was an advantage in working at 0° because the metals were mechanically least deformable at this temperature. The thermal expansions at four mean pressures, 5000, 10000, 15000, and 20000 were then obtained by successive readings at the five temperatures, up and down, the position of the piston being held fixed during a temperature excursion and therefore the pressure constant, except for the small changes due to the thermal expansion of the transmitting liquid. Distortion of the specimen under these conditions was practically eliminated, because of the very small movement of the transmitting liquid; and the recovery of the initial reading on returning to 0° was always very close. In any event, the mean of the readings with increasing and decreasing temperature should give the thermal expansion with sufficient accuracy. The manipulations involved in this procedure were slow, demanding for each reading the changing of the temperature of the bath and then waiting for temperature equilibrium; about six hours were necessary for the determinations of thermal expansion at a single mean pressure, as compared with two or three hours sufficient for an isotherm over the entire pressure range. Such long manipulations were undesirable, particularly at the higher pressures, because of shortening of the life of the cylinder and the possibility that the entire series of measurements would be ruined by an explosion. There seemed no way of avoiding this procedure, however, and most fortunately all the final thermal expansion measurements on the three metals, as well as the calibrating blank runs, were made with the same cylinder. This cylinder showed, however, toward the end of the measurements, unmistakable evidences of approaching failure.

The thermal expansions as directly determined were the differential expansions with respect to the steel envelope. In reducing to absolute expansion, the values of the thermal expansion of iron implicitly contained, but not explicitly stated, in the former measurements of compressibility at two different temperatures were assumed to be correct, and furthermore, as already explained, the results were extrapolated from 12000 to 20000 by the same second degree formula that had sufficed in the range up to 12000. This precise assumption is not a matter of much importance, however, because the thermal expansion of iron is small compared with that of the alkali metals, and the variation with pressure is relatively small. The figures assumed for the linear expansion of iron were 0.0000120 at atmospheric pressure and 0.0000110 at 20000. In making the final computations it was necessary to use corrections which had been determined from a run in which the specimen of alkali metal was replaced by a piece of pure iron. The reason for this was that it would not have been safe to assume that the thermal expansion of all parts of the envelope, which consisted of hard and soft steel and in addition a thin mica washer for insulation, was the same as that of pure strain-free iron. The corrections were so determined as to make the results with the blank run agree with the results assumed for pure iron. As a matter of fact, the corrections so found were of little importance.

In addition to permanent distortion in the specimens, another serious difficulty in getting accurate measurements was in the slight fluctuations in the manganin gauge. The difficulty was probably accentuated by the fact that the gauge was subjected to the same changes of temperature as the specimen. In the former measurements to 12000 the gauge was mounted in a separate cylinder, and maintained continually at room temperature, independent of the temperature of the specimen. The necessity for making the apparatus all in one piece now demanded that the gauge have the same temperature as the specimen. This demanded in the first place a determination of the pressure coefficient of the gauge as a function of temperature. This was done by comparing the gauge at each of the five temperatures against a standard manganin gauge, which had been calibrated in the regular way against the freezing pressure of mercury at 0° C and which was maintained continuously at room temperature. This comparison was made up to 12000 kg/cm^2. In this range the high pressure gauge was linear against the standard gauge at each temperature. The pressure coefficient is not, however, quite a linear function of temperature, but increases less rapidly at the higher temperatures. The coefficient was found to increase by 1.30 per cent from 0° to 50°, and by 2.04 per cent from 0° to 95°. Partly, perhaps, because of the temperature changes, partly because of the greater pressure range, partly because the wire was of smaller diameter than that which had been previously used, 0.076 mm in diameter instead of 0.134, so that viscous drag by the transmitting medium is greater, and partly because the manganin itself is from a different source, being of recent American manufacture rather than of German manufacture of 40 years ago, the permanent zero changes after application of pressure were inclined to be much greater and more capricious than in the previous work. In fact, the changes found at first were sufficiently great to affect seriously the accuracy of the thermal expansion measurements. A special process of seasoning was therefore adopted; this consisted in maintaining the wire at a temperature of 130° C continuously for a week, except that for a few minutes every morning the coil was cooled to the temperature of solid CO_2. This treatment was effective in reducing the zero wandering to a harmless amount. Thus, after the series of thermal expansion measurements of lithium and potassium, the zero had changed by an amount equivalent to 17 kg/cm^2, 0.085 per cent of the maximum range. The zero change after the runs with sodium was greater, but there was internal evidence showing that the change had mostly occurred at one definite place, so that correction could be easily applied for it.

The extension of the pressure scale from 12000 to 20000 by linear extrapolation of the manganin gauge readings is an unsatisfactory feature, but one which appeared necessary. However, it was possible by two lines of attack to convince oneself that the error so introduced is probably of negligible importance. The problem here is somewhat like that of finding a suitable method of extending temperature measurements into the region close to 0° Abs. and the methods adopted are also somewhat similar. If the extrapolated scales given by different phenomena agree, one may have considerable confidence in the results. The first method adopted consisted essentially in a comparison of the extrapolated scales given in terms of the effect of resistance on the resistance of several different metals. The metals chosen were iron, silver, and gold. Extrapolation of the results is complicated by the fact that the resistance changes of these metals are distinctly not of the first degree, nor even of the second degree within the errors of measurement. An ideal procedure would be to show that the same analytical expression represents the change of resistance as a function of pressure over the range up to 20000 that had formerly served to represent it up to 12000, assuming the linearity of the manganin over the entire range. One might feel considerable confidence if such an extrapolation were possible, because it would be highly improbable that deviations of all four metals would exactly conspire. As a matter of fact the situation could not be handled in quite this simple way, but this suggests the general idea of the method of approach. The details of the comparison will be found in the detailed presentation of data, and an estimate of the possible error of the linear extrapolation.

The second presumptive evidence as to the legitimateness of the extrapolation was obtained from the blank runs with pure iron. The results obtained from these runs were linear to a high degree of approximation at each of the five temperatures over the entire pressure range, with no hint of a change of trend between 12000 and 20000, so that for this additional reason considerable confidence may be felt in the extrapolation.

DETAILED DATA.

Resistance of Gold, Silver and Iron. As already stated, the primary purpose of these measurements was not to find how the resistance of these metals varies with pressure over the new pressure range, but rather to obtain some suggestion as to the legitimateness of measuring pressures above 12000 by assuming that the relation between pressure and the resistance of manganin, which had been shown by reference to a primary pressure gauge to be linear below 12000, continues to be linear between 12000 and 20000. For this purpose it was sufficient to make the measurements at a single temperature, 30°. The specimens measured were the identical samples which had been measured in 1917;[4] they had been kept since that time in cork stoppered test tubes, and showed no perceptible change. The wires were double silk covered, wound non-inductively into open coreless toroids; the resistance of gold, silver, and iron were respectively 18, 21, and 75 ohms. The three toroids, together with the manganin gauge, were attached one each to the four terminals of the four terminal plug, all coils being grounded in common to the cylinder. Measurements of resistance were made on the same Carey Foster bridge with which the pressure is regularly determined in terms of the change of resistance of the manganin.

It was not possible to get as clean cut results as had been hoped because of very perceptible hysteresis in the resistance of all three metals against manganin. Readings with increasing and decreasing pressure in all cases differed consistently by much more than the irregularity in the individual readings; the maximum differences between increasing and decreasing readings, in terms of the maximum change produced by pressure, were 0.74 per cent, 0.72 per cent, and 0.55 per cent, respectively, for gold, silver, and iron. Associated with the hysteresis were permanent changes of zero of the same order of magnitude. In view of the long period of rest since previous exposure to pressure, and the very elaborate seasoning of the manganin, and the further fact that the manganin did not show changes of zero, it is plausible to suppose that the hysteresis was not connected with the manganin, but with the other metals.

The mean resistance, that is the average with increasing and decreasing pressure, definitely could not be represented within the error of the readings by second degree relations in the pressure; but there were consistent departures always in the same direction, namely the maximum departure from linearity occurs at a pressure less than half the maximum pressure, and the curvature is greater at the low pressures than at the high pressures. The departures from a second degree relation were, however, in all cases slight, being greatest for iron, where the maximum departure of any observed point from that given by the second degree relation was 0.14 per cent of the maximum pressure effect. In view of the hysteresis, it did not seem worth while to attempt to reproduce the divergences by an analytical formula. The following are the second degree relations which best reproduce the actual results over the entire pressure range. The constants in these formulas are so chosen that the observed changes of resistance at 10000 and 20000 are exactly reproduced.

$$\text{Gold} \qquad \frac{\Delta R}{R_0} = -3.017 \times 10^{-6} p + 1.05 \times 10^{-11} p^2$$

$$\text{Silver} \qquad \frac{\Delta R}{R_0} = -3.575 \times 10^{-6}p + 1.90 \times 10^{-11}p^2$$

$$\text{Iron} \qquad \frac{\Delta R}{R_0} = -2.377 \times 10^{-6}p + 0.71 \times 10^{-11}p^2$$

These results are all at 30° C, and pressure is in kg/cm^2.

The best comparison with previous results is afforded by comparing the fractional changes of resistance at 12000 obtained now with those obtained formerly. The present fractional changes at 12000 for gold, silver, and iron, respectively, are − 0.0351, − 0.0402, and − 0.0275 against the previous values − 0.0346, − 0.0412, and − 0.0275.

Finally the question of the possible error in the extrapolation was crudely answered in the following way. The best second degree curve was passed through the experimental points up to 12000, that is, the constants in a second degree relation were so determined as to give the observed changes of resistance at 6000 and 12000. With the constants so determined the change of resistance at 20000 was calculated and compared with the measured value, which of course involved the linear extrapolation of the manganin. The changes of resistance calculated in this way were too small by 1.58 per cent, 0.95 per cent, and 1.24 per cent for gold, silver, and iron respectively, which means that the pressure calculated from a second degree formula made to fit approximately the observed changes of resistance of gold, silver, and iron in the range of direct pressure measurement up to 12000 would give pressures too large at 20000 by the amounts mentioned. In view of the known failure of the second degree relation to exactly reproduce the results in the range up to 12000, the discrepancies just found must be very generous upper limits to the true error; and I believe that we may finally conclude that the pressure obtained by a linear extrapolation of the manganin resistance is probably in error at 20000 by not more than a small fraction of one per cent.

Resistance of Black Phosphorus. This material was from a batch freshly prepared in the conventional way from white phosphorus at 200° C and 12000 kg/cm^2, the pressure transmitting medium being water. The original dimensions of the white phosphorus were 1.4 cm diameter and 10 cm long. The transition is accompanied by a 33 per cent decrease of volume. The structure of the resulting black phosphorus is coarsely granular at the upper end and at the lower end very fine grained and distinctly filamentary in character, the direction of the filaments presumably being the direction of relative motion during the transition. The fracture at the lower end is very similar to that of hematite in the form of the so-called "pencil ore." The specimen was cut from the lower end; some selection was necessary in order to obtain a piece free from cracks. The specimen was in the form of a rod of rectangular section, 2.1 x 1.7 mm, and about 2.5 cm total length. Measurements were made by the potentiometer method, using four terminals. The distance between potential terminals was 1.36 cm. The current terminals were bands completely girdling the specimen and making approximately uniform contact all around, so as to minimize end effects.

The specific resistance at 30° C at atmospheric pressure was 0.484 ohm cm; this is somewhat smaller than two values previously found which were 0.588 and 0.773.[5] The difference is perhaps not more than might be expected in view of the pronounced structural differences of different specimens. The temperature coefficient at atmospheric pressure is negative, the resistance at 75° being 35 per cent less than at 30°. This is not very different from the temperature coefficient shown by the two previous samples; the temperature coefficient varies less from sample to sample than does the specific resistance itself.

Two unsuccessful attempts to determine the pressure effect were made before the final successful attempt; one of these was terminated by rupture of the cylinder and the other by rupture of the insulating plug. The partial results obtained during the unsuccessful attempts were not inconsistent with those finally obtained. Successful runs were made at 30° and 75°. The initial application of pressure at 30° was accompanied by seasoning effects, the readings with decreasing pressure falling below those with increasing pressure and the zero resistance being permanently depressed by 16 per cent. The seasoning was practically complete with the first application of pressure; on the second application points agreed with increasing and decreasing pressure, the zero shift was only 0.5 per cent, and no point lay off a smooth curve by more than 2.3 per cent of the resistance at that point, the average deviation being much less. The basis of estimation of the smoothness of the results is necessarily different here from that usually employed because of the very large changes of resistance; the meaning of the statement just made is that when $\log_{10} R/R_0$ is plotted against pressure the maximum deviation from a smooth curve of any single point was 0.01, the total variation in the logarithm being more that 2.00. Log R/R_0 is given as a function of pressure at 30° and 75° in Table I.

TABLE I.

RESISTANCE OF BLACK PHOSPHORUS.

Pressure kg/cm^2	Log$_{10}$ R/R_0		Pressure kg/cm^2	Log$_{10}$ R/R_0	
	30°	75°		30°	75°
0	0.000	9.871	11000	8.687	8.677
1000	9.894	9.762	12000	8.554	8.554
2000	9.787	9.655	13000	8.424	8.439
3000	9.678	9.548	14000	8.298	8.325
4000	9.566	9.441	15000	8.182	8.217
5000	9.451	9.333	16000	8.078	8.118
6000	9.332	9.223	17000	7.994	8.037
7000	9.209	9.112	18000	7.920	7.971
8000	9.083	9.001	19000	7.875	7.920
9000	8.953	8.890	20000	7.838	7.883
10000	8.820	8.779			

Previously measurements have been made of the resistance of black phosphorus up to 12000 at 0°, 50°, and 100°. In the range common to the two sets of measurements the results are not dissimilar. Thus at 30° and 12000 kg/cm^2 the previous sample showed a decrease of resistance to 0.0333 of its initial value, whereas the resistance of the present sample under the same conditions decreases to 0.0358. The pressure coefficients and the temperature coefficients thus both agree much more closely than the specific resistances.

Three special features of the resistance require comment. In the first place there is the very large decrease of resistance, at 0° and 20000 kg/cm^2 the resistance being only 0.0069 of its initial value. In the second place there is the fact that the relative decrease is less at higher temperatures, and by so large an amount that the curves of actual resistance cross at about 12000. Above 12000 the temperature coefficient reverses sign and becomes positive. This decrease of temperature coefficient with rising pressure was also found formerly, but the effect was not so large, and the coefficient had not yet reversed sign up to the previous maximum of 12000. In the third place there is the complicated variation of pressure coefficient with pressure at constant temperature, and particularly the very rapid change of slope at high pressures. This is shown in Figure 2, in which is plotted the differences of log R/R_0 for pressure differences of 1000 kg/cm^2. Unless there is some very abrupt reversal of trend at pressures only a little above 20000, a smooth and relatively short extrapolation demands that the pressure coefficient reverse sign at about 23000, so that above 23000 the resistance may be expected to increase with rising pressure at constant temperature. Such a minimum of resistance has been established up till now only for some of the alkali metals and for barium.[6]

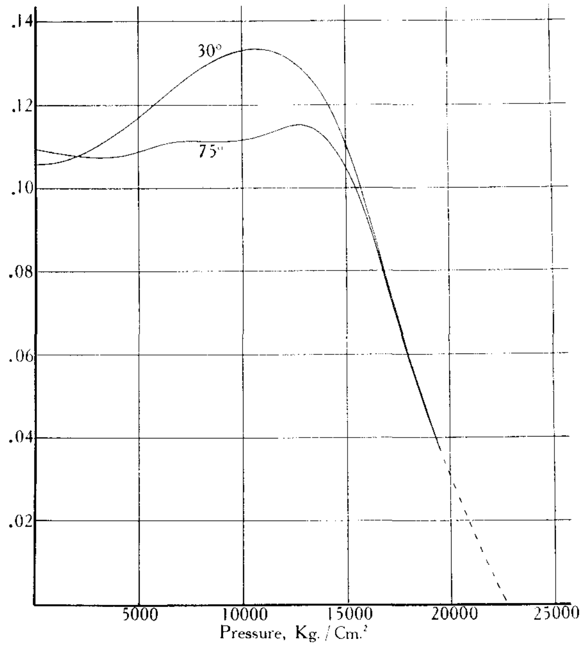

FIGURE 2. The first differences for pressure intervals of 1000 kg/cm² of $\log_{10} R/R_0$ of black phosphorus as a function of pressure at 30° and 75° C. The dotted part of the curve is extrapolated.

Resistance of Tellurium. This material is of interest because of the very large effect of pressure on resistance. It had previously been measured at − 183° and − 78° up to 7000 kg/cm², and at 0° and 95° up to 12000.[7] Measurements were now made at 30° and 75° up to 20000 on the identical specimens formerly used. There was no hysteresis in the readings nor permanent changes of zero after exposure to pressure. The readings at 30° C on the specimen with length inclined at 23.5° to the trigonal axis were the most irregular, the greatest departure of any single point being 0.02 on a logarithmic scale. The maximum departure of any point on the three other isotherms was less than 0.01, and the average deviation from smoothness perhaps 0.002.

Smoothed results for $\log_{10} R/R_0$ as a function of pressure and temperature for the two orientations are given in Table II. The first differences for thousand kilogram intervals are shown in Figures 3 and 4. An exact comparison with previous results is not possible because the temperatures of the two sets of readings were not the same, and resistance is far from a simple function of temperature, as

TABLE II.

Resistance of Single Crystal Tellurium.

Pressure kg/cm^2	Log R/R_0			
	23.5° orientation		86° orientation	
	30°	75°	30°	75°
0	0.000	9.704	0.000	9.697
1000	9.853	9.548	9.844	9.532
2000	9.709	9.405	9.691	9.377
3000	9.568	9.271	9.541	9.231
4000	9.430	9.145	9.395	9.094
5000	9.295	9.025	9.254	8.964
6000	9.165	8.910	9.119	8.841
7000	9.040	8.800	8.989	8.725
8000	8.921	8.693	8.865	8.615
9000	8.809	8.591	8.747	8.510
10000	8.705	8.496	8.634	8.410
11000	8.605	8.405	8.526	8.316
12000	8.510	8.318	8.423	8.227
13000	8.419	8.237	8.324	8.142
14000	8.332	8.161	8.230	8.061
15000	8.249	8.089	8.140	7.983
16000	8.170	8.022	8.053	7.908
17000	8.095	7.958	7.969	7.836
18000	8.025	7.898	7.891	7.768
19000	7.959	7.841	7.818	7.704
20000	7.897	7.789	7.752	7.644

Figures 2 and 3 of the former paper show. The best that can be done is to make comparison at the two temperatures most nearly equal, namely 75° and 95°. The former results may be reduced to 75° by linear interpolation between 0° and 95°, and the present results reduced to 95° by linear extrapolation from 30° and 75°, and the average taken of the two discrepancies thus obtained. In this way it may be found that the logarithm of relative resistance at 12000 given by the present set of measurements differs for both orientations by about 0.03 from that previously found, the direction of the difference being such that the changes of resistance with pressure are now greater than formerly. Such a discrepancy is beyond experimental error, and indicates that some permanent change has taken place in the specimen during the 17 months since the former measurements. This change is not important, however, in view of the very large change in resistance produced by pressure, the total change in log R/R_0 at 20000 being about 2.2.

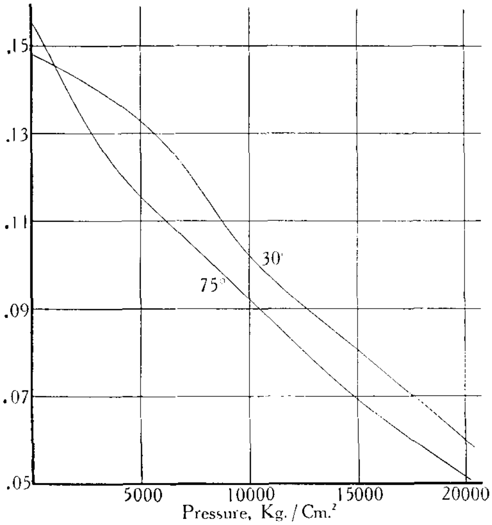

FIGURE 3. The first differences for pressure intervals of 1000 kg/cm² of $\log_{10} R/R_0$ of single crystal tellurium, the length of the rod inclined at 23.5° to the trigonal axis, as a function of pressure at 30° and 75° C.

The Table and the Figures show that the pressure effect is not greatly dependent on the orientation, the variation being much less than for some more highly metallic materials. One might perhaps be prepared to find a large dependence on orientation in view of the pronouncedly crystalline character of tellurium with its very marked cleavage. The results suggest that the electrical properties are not greatly affected by the crystal structure, a result which is perhaps to be correlated with the non-metallic character of tellurium.

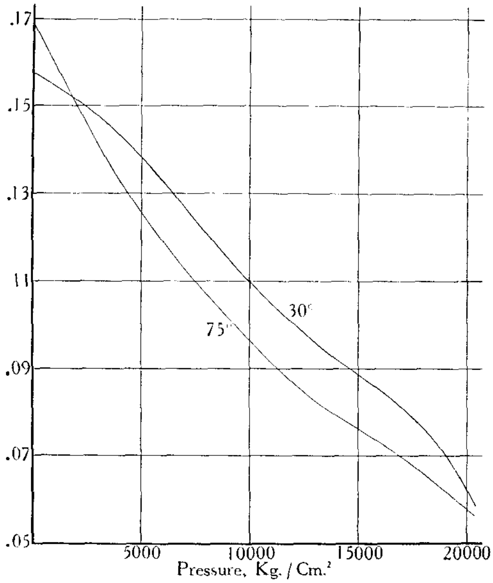

FIGURE 4. The first differences for pressure intervals of 1000 kg/cm^2 of $\log_{10} R/R_0$ of single crystal tellurium, the length of the rod inclined at 86° to the trigonal axis, as a function of pressure at 30° and 75° C.

Apart from the orientation effects, tellurium shows two of the striking effects of black phosphorus, although in less marked degree. There is in the first place a drawing together of the curves for different temperatures as pressure increases, the temperature coefficient at 20000 being only about one third as great as at atmospheric pressure. The temperature coefficient beyond 3000 drops nearly linearly with pressure; linear extrapolation indicates a reversal of sign of temperature coefficient at somewhat less than 30000. In the second place there is also a large decrease of pressure coefficient with increasing pressure, as shown in Figures 3 and 4. Because of the irregularity of these curves, extrapolation is more hazardous than extrapolation of the temperature coefficient, but a rough linear extrapolation indicates also a reversal of sign of pressure coefficient probably not far from 30000 and somewhat above it. That is, at pressures somewhat above 30000 resistance may be expected to increase with increasing pressure.

The total drop of relative resistance is about the same at 20000 for tellurium and black phosphorus; the relative resistance of tellurium at the points where temperature and pressure coefficients reverse sign will, therefore, be markedly less for tellurium than for black phosphorus.

Resistance of Copper Sulphide. This substance belongs to the class of semi-conductors, about which we have very little information with regard to behavior under pressure. The source of the material was Kahlbaum, "crystallized" fused lumps. A rod 0.35 cm in diameter and 1.21 cm long between potential terminals was formed by grinding and turning from one of the homogeneous lumps. Connections were spring clips of 0.008 inch steel wire, embracing the rod and pressing against opposite ends of a diameter in a small groove of V section cut around the rod. Measurements were made by the regular potentiometer method; the measuring current was about 0.1 amp. The measurements were never as definite with this material as with the metals; readings were not always perfectly steady, and on reversing current there were transient effects which took an unusually long time to disappear, although the final resistance for the two directions of current flow were usually close together. The irregular effects were much more prominent at 75° than at 30°.

The specific resistance at atmospheric pressure at 30° was 0.000818 ohm cm, and the average temperature coefficient of resistance between 0° and 100°, calculated by linear extrapolation of readings at 30° and 75° was − 0.00686.

The relative resistances as a function of pressure at 30° and 75° are plotted in Figure 5. At 30° the resistance is roughly a single valued function of pressure, without hysteresis between increasing and decreasing pressure. There is a sharp change in direction at 3000 kg/cm^2, where the resistance is about 0.95 its initial value. Above 3000 the rate of decrease of resistance with pressure suddenly becomes about ten times less; as pressure increases beyond 3000, however, this diminished rate becomes larger again, giving a curve for resistance against pressure concave toward the pressure axis, an abnormal effect shown by very few substances. At 75° on the first application of pressure, the same qualitative situation was again found, the discontinuity in slope now being displaced to about 2000, and at pressures above this the curve again being concave toward the pressure axis. At 75° it is evident however that there is an additional irreversible phenomenon; this seems to have been initiated between 10000 and 12000 with increasing pressure and to have progressed so far by the time that 2000 was again reached with decreasing pressure that the expected discontinuity at this point was suppressed. The points shown in the figure for decreasing pressure do not represent complete equilibrium, but at each point there was a slow creep of resistance downwards which had not entirely ceased when the reading was recorded. After the final reading at 75° the resistance at atmospheric pressure at 30° was redetermined, and was found to be displaced downward by almost exactly the amount of the total zero displacement at 75°. The internal change is, therefore, very much retarded if indeed not entirely inhibited at atmospheric pressure.

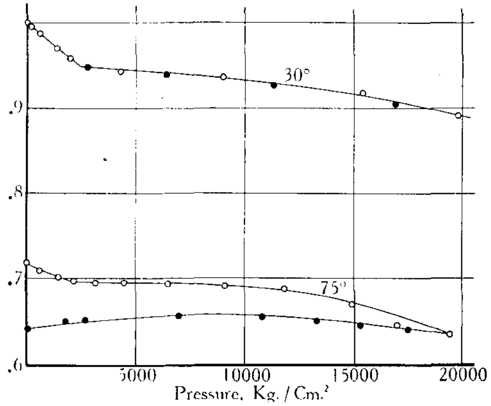

FIGURE 5. The relative resistance of Cu_2S as a function of pressure at 30° and 75° C. The open circles represent readings made with increasing pressure and the solid circles with decreasing pressure.

This substance should evidently be studied further; in particular the compressibility should be measured and also measurements made on material from other sources.

Compression and Thermal Expansion of Lithium. Many of the details of the measurements have already been described in the section on Apparatus and Technique. The source of the material was Kahlbaum. It was melted under Nujol in pyrex, taking great pains to keep the temperature as near the melting point as possible in order to avoid chemical attack on the glass. It was then filtered in the liquid state by forcing through a small aperture, cast into a rod of somewhat greater than the final diameter, and then extruded to the final diameter of 6 mm. The length of the sample as mounted in the piezometer was 5.9 cm. Two different sorts of measurements were made. The first was of the isotherms at 0°, 30°, and 75°. From these measurements good values of the compression at 0° were obtained, but the difference between isotherms was not accurate enough to yield good values for the thermal expansion. The second set-up yielded thermal expansion at approximately 5000, 10000, 15000, and 20000; it also yielded rough values for the isothermal compression at 0° which checked with the better values yielded by the other method with a maximum discrepancy of 4 per cent at the maximum pressure. The maximum departure of any point of the isotherm at 0° from a smooth curve corresponded to 0.4 per cent of the maximum change of volume at 20000. The irregularity in the individual determinations of thermal expansion corresponded to a probable error in the final results of the order of 1 per cent on the thermal expansion itself. Since the measurements were made at five temperatures, the thermal expansions as directly calculated give the thermal expansion as a function of the temperature range. The measurements were not accurate enough, however, to justify the attempt to specify the thermal expansion at any fixed pressure as a function of temperature range. It is true that the thermal expansion in the lower range, 0° to 30°, was consistently lower than that for any of the higher ranges, and this, taken at its face value, is evidence of an increase of thermal expansion with increasing temperature. However, the accuracy over the shorter ranges is less that that over the wider ranges, and since the expansion over the wider ranges did not vary consistently with temperature, too great significance should not be attached to the consistent behavior of the lower range. I believe it probable, however, that there is a slight increase of thermal expansion with temperature in the range of the measurements, and that the reversal of sign of $\left(\frac{\partial^2 v}{\partial \tau^2}\right)_p$ exhibited by all liquids hitherto measured does not occur in lithium in the present range. The thermal expansion tabulated in the following is the mean expansion obtained by taking a weighted average of the individual results for the ranges 0–30°, 0°–52.5°, 0°–75°, and 0°–95°, weighting these roughly 1, 2, 3, 4. The experimental values of the weighted mean expansions are shown in Figure 6; the value at atmospheric pressure was taken from I. C. T. The values listed in Table III were read from the smooth curve of Figure 6. These thermal expansions are calculated on the original length at 0° C and atmospheric pressure.

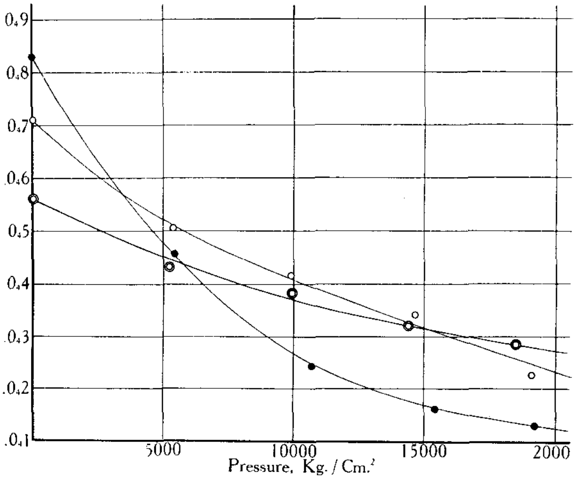

FIGURE 6. The mean linear thermal expansion between 0° and 95° C of lithium, sodium, and potassium as a function of pressure. The double open circles are the observed values for lithium, the single open circles for sodium, and the solid circles for potassium.

The volume compression at 0° listed in Table III may be compared with that formerly obtained.[8] Comparison at 10000 will sufficiently indicate the order of the agreement; the present value for $\Delta V/V_0$ is 0.0739; the former value, obtained by linear extrapolation of the determinations at 30° and 75°, and correcting the reduction from $\Delta l/l_0$ to $\Delta V/V_0$, was 0.0725. The former published value, with the incorrect reduction from Δl to ΔV was 0.0759. The mean linear thermal expansion at 10000, deduced from the former measurements after correcting the reduction from Δl to ΔV was 0.000044, against 0.000037 found now.

The former results can be represented over the pressure range up to 12000 by a formula of the second degree. Over the extended range up to 20000 a second degree expression is not quite adequate within experimental error, although it is adequate within two or three units in the last place. A second degree expression giving the correct $\Delta V/V_0$ at 10000 and 20000 gives too small Δv's below 10000 and too large Δv's between 10000 and 20000.

TABLE III.

VOLUME COMPRESSION AND THERMAL EXPANSION OF LITHIUM.

Pressure kg/cm²	Volume Compression $-\Delta V/V_0$ at 0° C	Mean Linear Thermal Expansion 0°–95° C
0		(000056)
2000	.0164	51_5
4000	.0320	47_3
6000	.0466	43_4
8000	.0606	40_0
10000	.0739	37_0
12000	.0866	34_5
14000	.0984	32_5
16000	.1094	30_6
18000	.1198	28_8
20000	.1296	27_3

Compression and Thermal Expansion of Sodium. The source of the material was Kahlbaum; it was filtered, cast, and extruded to the final dimensions. The length was 2.5 cm; two different diameters were used; 6 mm for the first runs giving isothermal compression, but for the thermal expansion measurements, where it was essential to secure the greatest possible freedom from distortion, the diameter was increased to 8.7 mm.

Most of the preliminary work in perfecting the final details was done with sodium; in all, the apparatus was set up with fifteen different fillings of sodium, and fifteen complete or partial runs were made. A number of different measurements of isotherms at different temperatures were made in the endeavor to determine the thermal expansion by taking the difference of complete isotherms, and at least four of these runs were good enough to yield values for the isothermal compression at 0°. The values given in the following were the mean of these four determinations; at both 10000 and 20000 the extreme departure from the mean of the four individual determinations was 0.22 per cent of the maximum effect. The thermal expansions tabulated in the following were obtained from a single set-up after the final method had been worked out; the self consistency of the thermal expansion over the different ranges of temperature was about the same as for lithium, although the irregularity was somewhat greater. No consistent variation of thermal expansion with temperature was found, and in the following only the mean values are given, weighted for range, as already explained.

In Table IV are shown the volume compression at 0° and the mean linear thermal expansion obtained from the smooth curve of Figure 6 drawn through the experimental points.

TABLE IV.

Volume Compression and Thermal Expansion of Sodium.

Pressure kg/cm²	Volume Compression $-\Delta V/V_0$ at 0° C	Mean Linear Thermal Expansion 0°–95° C
0		(.000071)
2000	.0295	62_2
4000	.0552	55_3
6000	.0779	49_5
8000	.0981	45_0
10000	.1165	40_8
12000	.1332	37_0
14000	.1488	33_7
16000	.1632	30_0
18000	.1767	26_5
20000	.1894	23_3

The general character of the agreement with the results previously obtained[9] is sufficiently indicated by a comparison of the results at 10000. Linear extrapolation to 0° of the results previously obtained at 30° and 75°, making the correct reduction from $\Delta l/l_0$ to $\Delta V/V_0$ gives $\Delta V/V_0$ at 0° and 10000 kg/cm² equal to 0.1134, against 0.1165 found now. The previous published value, in which the reduction was incorrectly made, was 0.1228. The mean thermal expansion at 10000, to be deduced from the former results, correctly reduced, was

0.000034 against 0.000041 found now. There is no question but that the present value is to be preferred.

Compression and Thermal Expansion of Potassium. The material was obtained from Kahlbaum. It was melted under Nujol, filtered through a fine hole, cast into a coherent perfectly clean rod of diameter somewhat greater than the final diameter, and reduced to the diameter of the finished specimen by extrusion. The final diameter was 0.87 cm and the length 1.77 cm. More or less complete runs were made with six different set-ups of the apparatus. The first of these was terminated by an explosion after a fairly complete determination of three isotherms; the results of four others were not sufficiently good to calculate, irregularities being due both to fluctuations in the gauge and to mechanical distortion of the specimen, which is particularly hard to avoid with potassium because of its great softness. The final run gave satisfactory results both for the isotherm at 0° and for the thermal expansion at four approximately constant pressures.

TABLE V.

VOLUME COMPRESSION AND THERMAL EXPANSION OF POTASSIUM.

Pressure kg/cm^2	Volume Compression $-\Delta V/V_0$ at 0° C	Mean Linear Thermal Expansion 0°–95° C
0		(.000083)
2000	.0571	67_0
4000	.1002	53_8
6000	.1347	42_7
8000	.1640	33_6
10000	.1890	26_0
12000	.2108	22_0
14000	.2300	18_3
16000	.2472	15_5
18000	.2626	13_8
20000	.2767	12_5

The volume compression at 0° and the linear thermal expansion are given in Table V. The volume compressions so tabulated are the weighted means of the two successful isotherms at 0°, giving the results with the two runs a weight inversely as the average departure of the readings from a smooth curve. These departures were 0.0034 and 0.0015, expressed as fractional parts of the total effect, the second run giving the best results. The difference between the results of the two runs, expressed as a fraction of the maximum effect, was 2 per cent at 10000 and 1.8 per cent at 20000, the better run giving the lower values for decrease of volume.

The thermal expansions given in Table V were obtained from the smooth curve of Figure 6, drawn through points representing the mean of the results for the four temperature ranges, weighted as already described. There was no consistent variation of thermal expansion with temperature at constant pressure, and it appears to be justified to retain only the weighted mean in the final results. The measured displacements at the high pressure end of the range, from which the thermal expansions were calculated, were smaller than for the two other alkalies, both because of the shorter length of the specimen and because of the absolutely smaller value of the thermal expansion. This was reflected in a greater irregularity of the results for the four temperature ranges; the apparently greater regularity of the experimental points for potassium as compared with sodium shown in Figure 6 is probably to a certain extent fortuitous.

The volume compression was previously determined only at 45° and up to 12000.[10] Using the value for the thermal expansion found now in order to extrapolate from 45° to 0°, and correcting the reduction from Δl to ΔV, the volume compression at 10000 formerly found was 0.1877, against 0.1892 found now. The published value, in which Δl was incorrectly reduced to ΔV, was 0.2150. The discrepancy due to the incorrect reduction is at its maximum for potassium, since it increases at an accelerated rate with increase of $\Delta V/V_0$.

The mean thermal expansion formerly found at 10000 was 0.000020, against 0.000027 found now. In general, the new values are better than the former values.

Discussion.

The principal points with regard to electrical resistance have already been discussed in the detailed presentation of data. In general comment, the resistance of black phosphorus and tellurium approaches that of the metals in so far as the reversal of sign of the temperature coefficient is concerned. If the reversal of sign of the pressure coefficient is considered to be a characteristic of all metals, as it is known to be for the alkali metals, then it is highly probable that black phosphorus and tellurium are metallic in this respect also at pressures not far beyond those actually reached. But the absolute value of the specific resistance, even at the highest pressures, still remains in the non-metallic range, being, for example, 20 times greater for tellurium at 20000 kg/cm^2 than for bismuth under normal conditions.

With regard to the alkali metals, it is to be remarked in the first place that there are none of the abnormalities in compressibility at high pressures, particularly for potassium, which were previously found and which were entirely due to the erroneous reduction from $\Delta l/l_0$ to $\Delta V/V_0$. The two compressibilities $\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_\tau$ and $\frac{1}{v_0}\left(\frac{\partial v}{\partial p}\right)_\tau$ both decrease smoothly with pressure, even for potassium, up to the highest pressure. For potassium the "instantaneous" compressibility, $\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_\tau$ has dropped at 20000 to about one third its value at atmospheric pressure, and the "actual" compressibility, $\frac{1}{v_0}\left(\frac{\partial v}{\partial p}\right)_\tau$, to about one quarter its initial value. Furthermore, there is now no crossing of the compressibility curves, but both "instantaneous" and "actual" compressibility increase from lithium to sodium to potassium over the entire range of pressure.

The thermal expansions, however, do show reversals of order. The thermal expansion drops with increasing pressure by a factor which increases from lithium to sodium to potassium, and the increase is more than sufficient to wipe out the initial superiority of potassium. The result is that above 3500 kg/cm^2 the expansion of sodium is greater than that of potassium, and above 15000 it is less than that of lithium, and above 5700 the expansion of potassium is less than that of lithium. This means that above 15000 the order of the alkali metals, arranged according to decreasing thermal expansion is: lithium, sodium, potassium; exactly the reverse of the order at atmospheric pressure. One is strongly reminded of the reversal of the order of the melting points of the alkali metals at high pressures already found; the two phenomena are doubtless intimately related.

Another feature is that the thermal expansion at 20000 of all three metals has dropped by a materially larger factor than has the compressibility. This is the exact reverse of the behavior usually found with organic liquids, the compressibility of which in the range up to 12000 decreases by a factor two or three times greater than the factor of decrease of thermal expansion.

A knowledge of thermal expansion is involved in an interesting speculation of G. N. Lewis as to limiting behavior at infinitely high pressure. Lewis has suggested[11] that it may be that the entropy of a crystalline phase tends toward zero at infinite pressure at all temperatures. In virtue of the thermodynamic relation $\left(\frac{\partial s}{\partial p}\right)_\tau = -\left(\frac{\partial v}{\partial \tau}\right)_p$ we have: $S\,(0, \tau) - S\,(p, \tau) = \int_0^p \left(\frac{\partial v}{\partial \tau}\right)_p dp.$ $S\,(0, \tau)$ may be determined by measurements at atmospheric pressure of specific heat as a function of temperature, assuming in accordance with the third law that entropy at 0° Abs vanishes. $S(0, \tau)$ has been so determined for a large number of substances and may be found in I. C. T. Lewis's hypothesis then demands that $\int_0^p \left(\frac{\partial v}{\partial \tau}\right)_p dp$ cannot be larger than $S\,(0, \tau)$, so that $\left(\frac{\partial v}{\partial \tau}\right)_p$ must decrease with increasing pressure fast enough to fulfill this condition. The integral may be approximately evaluated graphically. The result for potassium is that

$$S\,(0, 0^\circ\text{ C}) - S\,(20000, 0^\circ\text{ C}) = 2.03 \text{ kg cm/}^\circ\text{C gm.}$$

The value given in I. C. T. for $S\,(0, 0^\circ\text{ C})$ is 17.3 in the same units. Similarly for sodium $S\,(0, 0^\circ\text{ C}) - S\,(20000, 0^\circ\text{ C}) = 2.56$ kg cm/°C gm, and $S\,(0, 0^\circ\text{ C}) = 22.1$. The value for $S\,(0, 0^\circ\text{ C})$ is not tabulated for lithium, so that there was no particular point in calculating the change of entropy out to 20000; it is evident from the graph that it will be between that of sodium and potassium. The conclusion for sodium and potassium is that the change of entropy with pressure at 20000 at 0° C fails by a factor of about 8.5 to reach the theoretical limiting value. The state of zero entropy at 0° C must then occur at excessively high pressures. Even if $\left(\frac{\partial v}{\partial \tau}\right)_p$ for potassium should remain constant beyond 20000, zero entropy would not be reached below a pressure of 450,000 kg/cm^2. The general conclusion is that the zero state of entropy at ordinary temperatures is so very remote as probably not to impose any useful restriction on speculations as to behavior in the experimental range.

With the more accurate values of thermal expansion now available, it is possible to calculate more accurately than before the pressure at which the internal energy passes through its minimum with increasing pressure at constant temperature. Since $\left(\frac{\partial E}{\partial p}\right)_\tau = -\tau\left(\frac{\partial v}{\partial \tau}\right)_p -$

$p\left(\frac{\partial v}{\partial p}\right)_\tau$, this pressure is given by $p = -\tau\frac{\partial v}{\partial \tau}\Big/\frac{\partial v}{\partial p}$. Probably the easiest way to find this pressure is to plot $\tau\frac{\partial v}{\partial \tau}$ and $-p\frac{\partial v}{\partial p}$ against pressure and determine the point of intersection of the curves. It was found in this way that at 0° C the minimum energy of lithium occurs at about 5000 kg/cm^2, that of sodium at 4000, and that of potassium at 2300. These pressures are much lower than the corresponding pressures for harder metals such as iron, and furthermore are somewhat lower than obtained previously on the basis of earlier values of thermal expansion. The volume at which internal energy passes through a minimum is roughly the volume at which mean attractive and repulsive forces are in equilibrium, and this again should be roughly the same as the volume at 0° K at atmospheric pressure. This latter volume has not been determined with much accuracy, but there seems to be no question but that it is significantly larger than the volume at 0° C at the pressure of the minimum of internal energy. This seems to be the universal rule, and is doubtless connected with the compression of the force fields of the atom by external pressure.

At pressures beyond the minimum of internal energy the term $-p\frac{\partial v}{\partial p}$ becomes increasingly dominant over $\tau\frac{\partial v}{\partial \tau}$, so that at the highest pressures nearly all the mechanical work of compression is permanently retained as increase of internal energy, the energy flowing out as heat to compensate for the temperature rise produced by the compression becoming unimportant. This phenomenon is most marked, of course, with potassium; at 20000 kg/cm^2 all except 8 per cent of the mechanical work of compression is permanently retained. I have calculated approximately the total increase of internal energy of potassium at 0° C up to 20000 kg/cm^2 by a simple graphical integration, and it proves to be about 14.5 kg m for that amount of potassium which occupies 1 cm^3 at 0° C at atmospheric pressure. The total mechanical work of compression of the average organic liquid is not far from this.

SUMMARY.

The modifications in technique necessary in extending the pressure range from 12000 to 20000 kg/cm^2 are described.

The electrical resistance of silver, gold, and iron is found to extrapolate smoothly from 12000 to 20000, in such a way as to make it very probable that the manganin resistance gauge may be safely used up to 20000 kg/cm², assuming a linear relation between pressure and change of resistance, and obtaining the pressure coefficient from a single calibration at 7640 kg/cm², with a maximum error of a few tenths of one per cent.

The electrical resistance of black phosphorus and of single crystal tellurium in the 23.5° and 86° orientations is measured to 20000 at 30° and 75° C. Both of these substances show very large decreases of resistance, the resistance at 20000 being less than 0.01 of its value at atmospheric pressure. The temperature coefficient of black phosphorus reverses sign near 12000 kg/cm², and above 12000 is positive, like that of the metals. The temperature coefficient of tellurium (both orientations) also decreases markedly with pressure, but does not reverse sign, having a value at 20000 kg/cm² about one third of its value at atmospheric pressure. The rate of decrease of resistance with pressure drops very markedly with increasing pressure. With black phosphorus the drop is so rapid that a short extrapolation indicates that the resistance will probably pass through a minimum between 23000 and 24000 kg/cm². The extrapolation for tellurium is not so certain, but it is probable that at a pressure not much above 30000 its resistance will also pass through a minimum.

The resistance of Cu_2S at 30° decreases with pressure, with a discontinuity in the direction of change near 2500 kg/cm², above 2500 the rate of decrease being only about one tenth as large as immediately below 2500. Above 2500 the curve of resistance against pressure is concave toward the pressure axis, a very unusual phenomenon. The phenomena at 30° are approximately reversible. At 75° the same qualitative features as at 30° are shown on the first application of pressure, but above 10000 irreversible changes begin to take place, and the resistance with decreasing pressure does not retrace its former path, but lies below it, and the low pressure discontinuity is suppressed.

The change of volume of lithium, sodium, and potassium is measured at 0° C. The compressibility of these three metals drops smoothly, both with respect to pressure and with respect to each other, over the entire range. The relative drop of the compressibility of potassium is the greatest and that of lithium the least; at atmospheric pressure the compressibility of potassium is three times that of lithium and at 20000 kg/cm² 1.65 times.

The mean linear expansion between 0° and 95° C of the three alkali metals has been determined up to 20000 kg/cm². The expansion drops with increasing pressure by a factor considerably larger than does the compressibility. The drop for potassium is so much greater than that for sodium and lithium that there is a crossing of the curves, with the result that at 20000 kg/cm^2 the order of the expansions of lithium, sodium, and potassium is exactly the reverse of what it is at atmospheric pressure, potassium at 20000 appearing as the "hardest" and lithium as the "softest" metal. The same phenomenon is shown by the melting points.

The decrease of entropy of these three metals with pressure at constant temperature may be evaluated in terms of the thermal expansions. It appears that any vanishing of the entropy must occur at pressures excessively beyond the present experimental range.

I am indebted to my assistant Mr. L. H. Abbot for making the readings, which have often demanded a high degree of skill, to the Rumford Fund of the American Academy of Arts and Sciences for financial assistance in purchasing supplies, and to the Francis Barrett Daniels Fund of Harvard University for financial assistance with respect to the salary of Mr. Abbot.

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Proceedings of the American Academy of Arts and Sciences.

Vol. 70. No. 4.—May, 1935

THE LOWER PERMIAN INSECTS OF KANSAS. PART 7.

The Order Protoperlaria.

By Frank M. Carpenter.

With Two Plates.

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Proceedings of the American Academy of Arts and Sciences.

VOL. 70. NO. 4.—MAY, 1935.

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BY FRANK M. CARPENTER

WITH TWO PLATES.

THE LOWER PERMIAN INSECTS OF KANSAS. PART 7.

THE ORDER PROTOPERLARIA.[1]

BY FRANK M. CARPENTER.

Received February 4, 1935 Presented February 13, 1935

AMONG the Orthopteroid insects which Sellards described from the Elmo limestone in 1909 there were several closely related species which he placed in two families, Lemmatophoridae and Ortadae, and assigned to the Order Protorthoptera. In 1928, after working over the fossils in the Yale collection from this formation, Tillyard redescribed and revised the arrangement of these species, establishing for them the new order Protoperlaria, characterized by the presence of wing-like prothoracic expansions and considered by him to be allied and ancestral to the Recent stone-flies (Perlaria).

These species make up a very large part of the insect-fauna of the Elmo limestone, including at least twenty per cent of all the specimens which have been collected. In the Yale collection Tillyard found about 210 specimens; in the Sellards collection I find 42 specimens (in addition to the types), and in the Harvard collection more than 600 specimens. The occurrence of so many individuals is almost certainly due in large measure to the fact that these species were aquatic in the nymphal stages and bred in the same body of water which deposited the limestone in which they are preserved. That such was the case is demonstrated by the presence of many nymphs which undoubtedly belong to these insects.

This large series of fossils, representing only seven species, has enabled us to ascertain a great deal more about their body structure than is usually the case with fossil insects; in fact, we can safely say that at least two of these species are more completely known than any other extinct insects which have been found, with the possible exception of some of those preserved in the Tertiary ambers. Such a knowledge of the body structure is particularly helpful in the study of these specific fossils, since their position in the Orthopteroid series of insects would not otherwise be clear. It is mainly because of our lack of knowledge of the body structure of the Palaeozoic Orthopteroids in general that the classification and relationships of those insects are so obscure and the Order Protorthoptera merely a heterogeneous mixture of species of uncertain affinities. Sellards was perfectly justified, therefore, in placing the fossils now known as Protoperlaria within the Protorthoptera, since he knew nothing of their body structure; and since in the Elmo limestone there are many Orthopteroid insects, apparently Protorthoptera in the true meaning of the word, possessing wings almost identical with those of the Protoperlaria.

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[1] This series of studies has been aided by grants from the Carnegie Foundation, the National Academy of Sciences, and the Milton Fund of Harvard University.

Martynov, in the course of his study of the Permian insects of Russia, was so impressed by the similarity between the wings of the Lemmatophoridae (including the Ortadae) and those of several other families of Orthopteroid insects in the Kansan and Russian Permian, that he grouped all of these families into a new order, Miomoptera (1927). Tillyard, however, contends (1928) that the Order Miomoptera is only another assemblage of unrelated forms, established upon specific and even individual characteristics. In 1930, after a description of additional fossils from the Permian of Russia, Martynov redefined the order Miomoptera and maintained that the various families included in that order (Atactophlebiidae, Lemmatophoridae, Liomopteridae, Probnisidae, and Palaeomantidae) are really closely related to each other and "differ chiefly in the degree of specialization and reduction of the wing-venation."

The principal weakness in Martynov's view lies in the nature of the evidence which he uses to demonstrate the close relationship between the several families of the order Miomoptera. As he himself states, *this relationship is expressed chiefly in the degree of specialization and* reduction of the wing venation, without regard for the rest of the anatomy of the insects concerned. Of the five families included in the order, one, Probnisidae, is known to Martynov only by Sellards' superficial description of the wings; and the same is true of the Liomopteridae, although Martynov also placed here one hind wing (Haplopterum) from the Russian Permian. The family Lemmatophoridae, which has been discussed by Tillyard (1928), was known to Martynov at the time when he originally established the order Miomoptera (1927) only by Sellards' brief description of the wings. The family Atactophlebiidae is known by the wings of one species from the Russian Permian; and the family Palaeomantidae, although present in both the Russian and the Kansan Permian, is chiefly represented by wings, only a few body structures having been found.[2] Fortunately, in the collection of Kansan Permian insects at the

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[2] In Part 6 of this series of papers (1933) I reviewed the evidence which indicated that the family Palaeomantidae (Delopteridae) was actually a member of the order Copeognatha, as originally believed by Tillyard.

Museum of Comparative Zoology there are many specimens of Liomopteridae and Probnisidae and related families which show the body structure in complete detail. A study of these specimens has convinced me that Martynov's attempt to place the three families Lemmatophoridae, Probnisidae, and Liomopteridae in a single order is not justifiable. The evidence for this conclusion will not be presented here, but will be reserved for a subsequent paper in this series dealing with the two latter families.

In any discussion of Palaeozoic Orthopteroids, however, it should be borne in mind that there is room for considerable difference of opinion regarding the limits of the various orders and other taxonomic divisions; for these particular ancient insects are very close to the progenitors of many of our existing orders, which although perhaps more or less widely divergent at present, converge rapidly as we go back through the Mesozoic, and nearly, if not actually, meet in the Lower Permian. In this case, it is not merely lack of complete knowledge of the extinct insect's anatomy which gives rise to different opinions of its affinities, but the difficulty of drawing lines between one group and another.

Some diversity of opinion has arisen over the ordinal name of the Lemmatophoridae. Tillyard claims (1928, p. 348) that his name Protoperlaria takes priority over Martynov's name Miomoptera (1927) for an order based wholly or partly on the Lemmatophoridae, since he published a photograph of a specimen of Lemmatophora in 1926, stating in the caption under the photograph that it was a representative of a new order, Protoperlaria. Martynov, however, contends (1930) that since Tillyard's paper did not contain any diagnosis of the order, the name Miomoptera proposed by him in 1927 has priority over Protoperlaria, which was not formally proposed until 1928. Unfortunately, the question of the priority of ordinal names is not considered in the Code of Zoological Nomenclature, but I believe that Tillyard's stand is the more logical one. In this connection, it is a matter of much significance that Tillyard and Martynov had in mind two very different orders of insects. Tillyard conceived the Protoperlaria as typically represented by the family Lemmatophoridae, and as ancestral only to the Recent Perlaria. Martynov, on the other hand, had in mind an order typically represented by the peculiar family Delopteridae (Palaeomantidae), and ancestral to the Embidaria, as well as the Perlaria, and various extinct families.[3]

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[3] For a discussion of the relationships and synonymy of the family Delopteridae, see part 6 of this series, p. 450–461 (Proc. Amer. Acad. Arts and Sciences, **68** (11), 1933).

Since, as I shall show below, the members of the family Lemmatophoridae are so far removed structurally from the other Permian Orthopteroids that they require a separate order for their reception, it seems logical to use the name Protoperlaria for that order rather than Miomoptera.

Although Tillyard has already given a diagnosis of the order Protoperlaria, it is necessary for us to revise many of his statements and to redefine the ordinal characteristics. He considered the wing-like expansions on the prothorax of these insects to be an ordinal feature, asserting (1928, p. 186) that such organs are never found in the true Protorthoptera and are previously known only in the Palaeodictyoptera and Protohemiptera. But having worked over all of the Permian insects in the Harvard collection, I find that the majority of the Orthopteroid insects in the Elmo limestone possessed prothoracic lobes fully as large as those of the Lemmatophoridae. The presence of these lobes in the various Permian Orthopteroid insects and the similarity of their wing venation to that of the Lemmatophoridae greatly increases the difficulty of separating the latter insects from the former, and is a strong point in favor of grouping them all in one order, as was done by Martynov. The obvious step, perhaps, would be to place all these species possessing prothoracic expansions into the order Protoperlaria, conforming with Tillyard's original view of the occurrence of the lobes in these insects. But a study of the undescribed Permian Orthopteroids in the Harvard collection, including those with the prothoracic expansions and a wing venation similar to that of the Lemmatophoridae, reveals the fact that most of the families, if not all, *consist of species with a fully developed external ovipositor in the female.* The presence of an ovipositor in these insects is of great significance, since it demonstrates that their mode of development was entirely different from that of the Lemmatophoridae, which (like the Perlaria) not only lacked an external ovipositor, but were aquatic in the nymphal stages. It seems to me, therefore, advisable to restrict the order Protoperlaria to include only the species that lacked an ovipositor and were aquatic in the nymphal stages, since these clearly were in the direct evolutionary line or very nearly in the direct line of the Perlaria; whereas the other Orthopteroid insects, which possessed an ovipositor, were part of a very different branch of the Orthopteroidea, leading to the true Orthoptera.

Restricted in this way, the Order Protoperlaria includes a series of small and medium sized insects, having a wing expanse of ten to forty millimeters. The antennae were long and multisegmented; eyes large but not so prominent as in existing Perlaria; ocelli were probably present. The prothorax possessed a pair of wing-like lobes, covered with hairs. The meso- and metathoracic segments were large and flattened. The venation of the fore wing was simple: Sc terminated on the costal margin beyond the middle of the wing and was connected to the margin by a series of oblique cross-veins; Rl was unbranched, Rs either simple or forked or occasionally three-branched; both MA and MP were present, MA being unbranched (rarely forked), MP being either simple or forked or even three-branched; the proximal half of MP was obsolescent in all species; CuA was a very strong vein, having three and occasionally four branches (rarely only two); CuP was obsolescent, being reduced to a straight *vena dividens.* 1A and 2A were present. The hind wing was slightly shorter than the fore but had an enlarged anal area. Sc terminated on the costal margin and costal veinlets were probably present in some species; Rl was unbranched, Rs either simple or forked; MA was unbranched, MP either simple or forked; CuA was a strong vein, but reduced to two branches; CuP was very weak and obsolescent; the anal fan contained four main mains, consisting of 1A and derivatives of 2A; the first branch of 2A was forked. The venation of both wings, but of the fore pair especially, was very variable within the species, particularly in the amount of fusion between MA and Rs. *The tarsi of all legs were 5-segmented* (not 3-segmented, as stated by Tillyard); the hind legs were considerably longer than the others. The abdomen was rather small in comparison with the rest of the body and contained ten segments visible from above, the first nine segments bearing (in some species at least) a pair of small lateral processes resembling vestigial gills. Cerci were present and well developed. The nymphs were aquatic and resembled in general structure the nymphs of Recent Perlaria; they possessed well developed lateral abdominal gills.

The order Protoperlaria, as defined above, includes only the family Lemmatophoridae, from the Lower Permian of Kansas. Martynov (1930, p. 1116) has placed in this family the genus Kazanella, with two species (*rotundipennis* Mart. and *compressa* Mart.), both known only from fragments of wings. These wings, however, are almost identical with those belonging to certain of the undescribed Orthopteroids from the Lower Permian in the Harvard collection which possess the ovipositor previously mentioned. I therefore exclude Kazanella from the family Lemmatophoridae and the Protoperlaria as a whole, and refer it to the Protorthoptera. G. Zalessky (1933, p. 129) has also included in this order the family Caenoptilonidae, containing the single species *Caenoptilon minutum* Zall., from the Permian of Russia. The unique specimen on which this species was based is so poorly preserved and so badly distorted, as indicated by the waved and jumbled veins in Zalesky's figure, that its assignment to any order is uncertain. At any rate, it is not a member of the Protoperlaria, as this group is defined above.

At present there seem to be but five genera in the family Lemmatophoridae: Lemmatophora, Lisca, Artinska, Paraprisca, and Lecorium, all erected by Sellards in 1909. Several other genera as well as families were also established by Sellards for species now included in the Lemmatophoridae, but these were based entirely upon individual variations, resulting from the marked instability of the venation. In 1927, with the aid of a grant from the National Academy of Sciences, I was enabled to study Sellards' type specimens at Austin, Texas, and subsequently sent photographs of the types to Dr. Tillyard, who with their aid straightened out the taxonomy of Sellards' species (Tillyard, 1928). I agree with his conclusions on the synonomy of these genera except for that regarding Lisca, which he synonymized with Lemmatophora. He also erected a new genus, Sellardsia, but this is undoubtedly identical with Lecorium, as I shall show later. The five genera mentioned above fall readily into the two following groups, which for convenience I designate as subfamilies:

I. Subfamily **Lemmatophorinae.** Fore wings broad, their length being about two and one-half times their width, never three times; hind wing with a deep incision on the margin at the termination of CuP; prothoracic lobes large, extending over the anterior half of the mesothorax.

1. Radial sector forked . . . . *Artinska*
   Radial sector unbranched 2
2. Subcosta remote from costal margin at the base of the wing; radial sector arising at about the middle of the wing; Rl of fore wing with a slight upward bend at the origin of the radial sector; Rl straight in pterostigmal region; cerci long; hind tarsal segments unequal in length . . . . *Lemmatophora*
   Subcosta close to costal margin at base of fore wing; radial sector of fore wing arising well proximad of the middle of wing; Rl not bent at the origin of Rs; Rl curved in pterostigmal region; cerci short; hind tarsal segments equal . . . . *Lisca*

II. Subfamily **Paraprisciniae.** Fore wings narrow, their length being more than three times the width and sometimes nearly four times; hind wing with only a slight incision on the hind margin at the termination of CuP, the margin of the anal area being almost continuous with the rest of the wing margin; prothoracic lobes small, hardly reaching to one-fourth the length of the mesothorax.

R1 straight, not bent at the origin of the radial sector, not curved in the pterostigmal region; CuA entirely free from M; all legs slender, the hind pair tenuate; cerci short, about one half the length of the abdomen........... *Paraprisca*

R1 bent slightly at origin of the radial sector and curved in pterostigmal region; CuA always coalesced with M; all legs stout; cerci fully as long as abdomen............. *Lecorium*

Subfamily LEMMATOPHORINAE.

Genus *Lemmatophora* Sellards.

Lemmatophora Sellards, 1909, Amer. Journ. Sci., (4) **27:** 162.
Lemmatophora Tillyard, 1928, Amer. Journ. Sct., (5) **16:** 187.

Fore wing: broad, costal margin curved, apex rounded; Sc remote from margin at the base, terminating at the proximal end of the pterostigma; R straight as far as the origin of Rs, at which point R1 diverges upwards slightly and then makes an abrupt downward bend at the proximal end of the pterostigma; Rs unbranched; MA unbranched, rarely forked, arising near the middle of the wing; MP forked (rarely 3-branched). *Hind wing:* very broad, costal margin nearly striaght, apex bluntly rounded, hind margin with a deep incision at end of CuP; R1 curved below the pterostigmal region; Rs unbranched, originating near the middle of the wing and coalescing with MA for a short distance; MA unbranched; first branch of 2A forked.

Body structure: antennae short, only a little longer than the head and thorax combined, all segments except the first two subequal; front and middle legs short, hind legs much longer; first segment of hind tarsus much longer than the other segments; cerci long.

The genotype of Lemmatophora is *L. typa* Sellards. In my opinion this is the only species in the genus, although Tillyard has placed here *Lisca minuta* Sellards. In view of the very different body structure of the two insects, however, I believe that the species are generically distinct.

Lemmatophora typa Sellards.

Figure 1; plate 1, fig. 1; plate 2, fig. 3, 4.

Lemmatophora typa Sellards, 1909, Amer. Journ. Sci., (4) **27**: 162.
Lemmatophora typica Tillyard,[4] 1928, Amer. Journ. Sci., (5) **16**: 191.
Lemmatophora typica Tillyard, 1928, *ibid.*, p. 318 (full synonymy given here and in the preceding reference).

Fore wing: length 5.5–9 mm.; width, 2.0–3.3 mm.; Sc close to R at the base of the wing; 9–16 veinlets in the wide costal space; pterostigmal region usually traversed by several veinlets, greatly variable in shape and number; two strong cross-veins between Sc and R; 4–6 cross-veins between Rs and R1; one of these sometimes very oblique and long, having much the appearance of a branch of Rs; MA originating proximad of the origin of Rs, nearly always unbranched and generally free but occasionally coalesced with Rs for a variable distance; MP usually deeply forked; CuA formed in the manner characteristic of the genus, there being considerable variation in the length of the branches; occasionally CuA bears four branches or is reduced to two; at the first fork of CuA there are two or three prominent cross-veins leading to M; the two anal veins are divergent and are connected by two stout cross-veins, the outer one sigmoidally curved. *Hind wing:* length, 5.7–8.4 mm. Sc remote from the margin at the base, and even further away near its middle point; about 6 weak costal veinlets; pterostigma well developed; Rs arising a little proximad of the middle of the wing and soon fusing with MP for a short distance; MA arising almost directly below the origin of Rs; MP continuing in a straight line the basal part of M; CuA arising at the very base of the wing and soon fusing with M for a short distance, forking directly below the origin of Rs; CuP a straight and weak vein, not very concave and distally crowded between CuA2 and 1A.

The fore wings of most of the specimens have indications of color markings and probably those wings which do not show such coloration have lost it during the course of preservation. The arrangement of the markings is clearly shown in the photograph in figure 1, plate 1. The most prominent spot is the one at the first fork in CuA; the others are more variable in position and extent, and those margining the cross-veins may be entirely absent. Well preserved specimens also show that the wing surface was heavily covered with microtrichia, as in all the other Protoperlaria.

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[4] Tillyard (1928) changed the name of this insect to *typica* on the grounds that there is no such word as *typa*. Since there is nothing in the Zoological Code of Nomenclature which permits change to be made on this basis, I have used Sellards' original name.

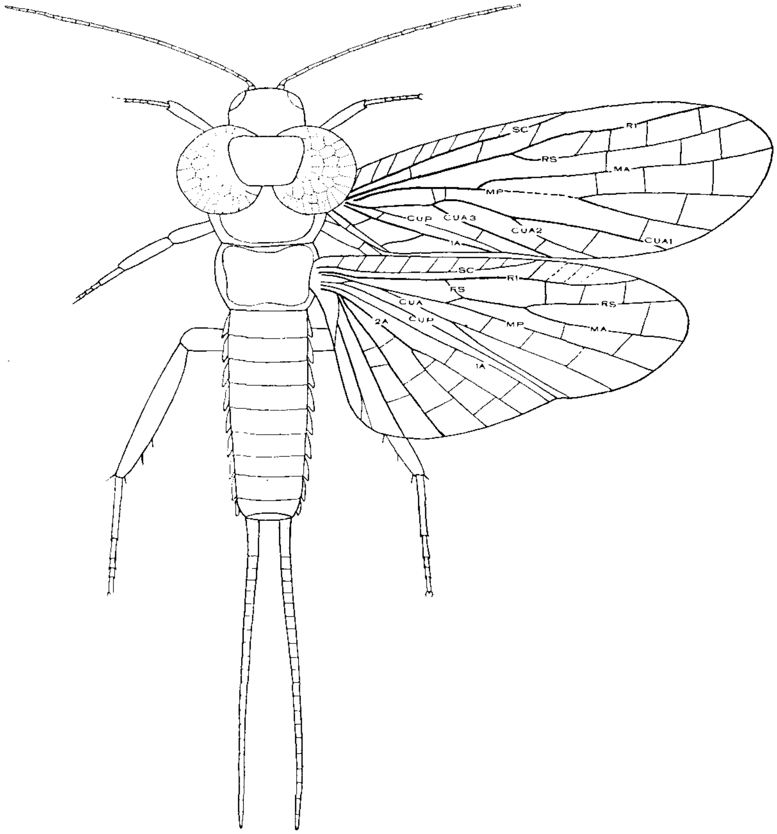

FIGURE 1. Reconstruction of *Lemmatophora typa* Sellards, based mainly on specimen No. 3536*ab*, Museum of Comparative Zoology. Sc, subcosta (−); Rl, radius (+); Rs, radial sector (−); MA, anterior media (+); MP, posterior media (−); CuA, anterior cubitus (+); CuP, posterior cubitus (−); 1A, first anal (+); 2A, second anal (+).

Body structure: length of body, including cerci, 11–13 mm.; length of antennae 5 mm., and of cerci, 5 mm. Antennae with 23–25 segments; first tarsal segment of the fore and middle legs equal in length to the combined third and fourth, which are subequal; last segment twice as long as the fourth; hind tibia at least twice as long as the middle and fore tibia and somewhat swollen; first tarsal segment of hind leg as long as the rest of the tarsus, second segment as long as the third and fourth combined, which are equal; last segment about the same length as the second.

The holotype of this insect was a fore wing, No. 1162 in the Sellards collection. Since this specimen (as well as the types of the synonymous species) has been lost, I designate as the neotype specimen No. 3536ab in the Museum of Comparative Zoology; this consists of a complete insect (plate 1, figure 1), collected by the writer in the lower layer of the limestone in 1927.

Lemmatophora typa is unquestionably the commonest insect in the Elmo limestone. In the Yale collection there are 86 specimens, in the Sellards collection (in addition to the original types) 25, and in the collection of the Museum of Comparative Zoology more than two hundred specimens, making a total of well over three hundred individuals of this species. Adult specimens are only about half as numerous in the upper layer as in the lower layer of limestone, although nymphal forms which probably belong to this species are much commoner in the upper. The following are the more important specimens in the Harvard collection; all are from the lower layer of limestone except No. 3541ab. Nos. 3527, 3528, 3529ab, 3530ab, 3531ab, 3535ab, and 3541ab, all perfectly preserved fore wings; No. 3532ab, consisting of fore and hind wings, and portions of the body, the prothoracic lobes being very clear; No. 3533ab, one fore wing and part of the body; 3536ab, the neotype, a very nearly complete insect, showing fore and hind wings, general body structure, one complete antenna, one fore leg and one hind leg (see figure 1, plate 1); No. 3537ab, nearly a complete insect, showing two fore wings and most of hind wings, general body structure, both antennae, one middle and both hind legs; No. 3538ab, portions of wings and the body, the antennae being especially fine; No. 3539, nearly complete, showing particularly well the thorax and the prothoracic wing pads; No. 3540ab, portions of the wings and body; 3542, the wings and several parts of the body; 3543ab, one fore wing, head, one antenna, and thorax, all body parts being perfectly preserved; 3544ab, one fore wing and portions of the abdomen, the cerci being complete; 3545ab, fore and hind wings, and portions of the body, the head, cerci and prothoracic lobes being very clear; No. 3547, fore wing, portions of thorax and head; 3548ab, fore wing, thorax and head (excellent);

No. 3549ab, fore and hind wings and almost the whole body, showing especially well the prothoracic lobes and head. In the Sellards collection there are three specimens of fore wings which are complete and very well preserved: Nos. 697, 331, and 329.

There are several features of the body structure of this insect which are of much interest. Some of these have been already mentioned by Tillyard, but the collection in the Museum of Comparative Zoology is so rich in specimens showing the body that I have considered it advisable to add a short discussion of this subject:

1. Head. In none of the specimens which I have seen, including those in the Yale collection at the Peabody Museum, has it been possible for me to make out a satisfactory frontal view of the head, although this has been figured by Tillyard in his account of the Yale fossils. All the Harvard specimens which are preserved in a dorsal-ventral position have the head in an attitude corresponding to that usually found in Recent Perlids, the frontal region being hidden from above. The maxillary palpi are preserved in several specimens in lateral position and they appear to be 4- or 5-segmented. The eyes, although large, do not protrude nearly as much as in the Perlaria and they are situated further forward.

2. Thorax. The pronotum is large and subcordate; the remainder of the prothorax is covered by the large prothoracic lobes. The latter are not attached merely to the sides of the pronotum, but extend nearly to the mid-line in the front and rear. These lobes almost certainly arise from beneath the pronotum itself, as can easily be seen in specimens preserved in a lateral position. Their reticulated network has all the appearances of being formed of true veins, but it is more likely composed of pigment bands, as suggested by Tillyard; at any rate, the size and arrangement of the cellules forming the network is very variable. The whole surface of the lobes is covered with minute hairs. The mesonotum is flat and subcircular; it conceals nearly the whole of the mesothorax as seen from above. The large metanotum is shaped very differently from the mesonotum, each side being concave, the anterior and posterior borders especially so. Specimens consisting of the three thoracic segments broken away from the rest of the insect and isolated on the rock are not uncommon in the limestone and can easily be recognized by the characteristic shape of the metanotum. The fore legs are decidedly short, the middle pair only slightly longer, and the hind pair much longer. The tibia of the fore leg is about 1 mm. long, while that of the middle leg is 1.2 mm. long, and that of the hind pair 2 mm. There are unquestionably five

tarsal segments in this species (as in all other members of the family Lemmatophoridae). Tillyard, who described and figured all tarsi as having only three segments, was apparently misled by the obscure condition of preservation of the fossils which he studied. Professor Dunbar and I have examined carefully the Yale specimens with particular reference to the tarsi and both of us have been unable to find any definite evidence of the number of tarsal segments in these specimens. Since several of the fossils in the Harvard collection (e. g., Nos. 3536ab and 3537) show the five tarsal segments very clearly (see figure 3, plate 2), there can be no doubt as to the number of segments. This, of course, is particularly interesting, since all known Recent Perlaria have only three segments. Tarsal claws and the empodium are well developed, as can be seen in the photograph of the tarsus of specimen No. 3536 (figure 3, plate 2).

3. Abdomen. The lateral gill-like processes on the abdominal segments can be made out in several of the Harvard specimens, although specimen No. 5147 in the Peabody Museum shows them best. These are undoubtedly vestiges of the larger and functional gills present in the nymphal stages. The cerci are long, usually much longer than the abdomen;[5] they are broad basally, but thin and delicate distally. As in Recent Perlaria the segmentation at the base is obscure, though clear beyond that point. In none of the many specimens of *typa* which I have examined are there any indications of the presence of dorsal and ventral valves, which are very obvious in Paraprisca and Lecorium.

Since the instability of the venation of *typa* has already been thoroughly discussed by Tillyard, there is no occasion for further comment on this subject, except to call attention to one variation not seen by him. That is the condition in which CuA has only two branches, CuA1 and CuA2 being united. Such a formation of the cubitus is not common in *typa* or any of the Lemmatophorinae, but is frequently found in the Paraprisciniae, as I shall point out later.

Genus *Lisca* Sellards.

Lisca Sellards, 1909, Amer. Journ. Sci., (4) **26**: 163.

Fore wing: costal margin curved slightly, apex rounded; Sc close to margin for its whole length, including the base, remote from R1 and terminating beyond the base of the pterostigma; R somewhat straighter than in *typa*, there being little change in direction, if any, at the origin of Rs; Rs originating well proximad of the middle of the wing, unbranched; MA unbranched or occasionally forked; MP deeply forked, rarely three-branched or unbranched. *Hind-wing:* costal margin nearly straight, apex bluntly rounded, hind margin with a deep incision at the end of CuP; Sc nearly straight; Rs arising close to base of wing and either free from MA or coalesced with it.

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[5] In the specimen (No. 5115) on which Tillyard based his figure of *typa* (p. 188, 1928), the cerci were broken off a considerable distance before the natural end; consequently in his drawing they are shown much shorter than in mine.

Body structure: antennae long, nearly twice as long as the head and thorax combined; all segments except the first two subequal; front and middle legs short, hind legs much longer; all segments of hind tarsus short and equal in length; cerci short, only about one-half as long as the abdomen.

Genotype: *Lisca minuta* Sellards.

This genus is similar to the former in respect to the unbranched Rs and the incised hind margin of the hind wing; but it differs particularly in the proximity of Sc to the costal margin, the early origin of Rs in both wings, as well as in certain body features, such as the short cerci, long antennae, and the short and equal hind tarsal segments. The latter characteristic is unique among the known species of the family Lemmatophoridae.

Lisca minuta Sellards.

Figure 2.

Lisca minuta Sellards, 1909, Amer. Journ. Sci., (4) **26**: 163; fig. 21.
Lemmatophora minuta Tillyard, 1928, Amer. Journ. Sci., (5) **16**: 215; fig. 16–18.
Lemmatophora reducta Tillyard, 1928, *ibid.*, p. 219; fig. 19.

Fore wing: length, 4.5–7.2 mm.; width, 1.5–2.5 mm. Costal veinlets between Sc and margin weakly developed or absent altogether; pterostigmal region usually traversed by several veinlets; 5–7 weak crossveins between R and Sc; Rs arising about one-fourth the wing length from the base and free or coalesced with MA for a variable distance; MA arising proximad of the middle of the wing, usually proximad of or directly below the origin of Rs; MP usually forked almost to the middle of the wing, but occasionally three-branched or simple; CuA usually with three branches, sometimes with two or four; 1A and 2A present, both very variable in form. *Hind wing:* length, 4.5 mm.; costal veinlets apparently absent; Rs arising almost at the very base of the wing; MA and MP unbranched; CuA forked to about half its length.

Body structure: length of body, including cerci, 6 mm.; antennae 3 mm. long, with about 28 segments;[6] cerci, 1.5 mm. long. Fore leg (preserved in specimen No. 3554), 3 mm. long; femur short and thick; first tarsal segment as long as rest of tarsus. Middle leg (preserved in specimen No. 3551), 3.5 mm. long; first and fifth tarsal segments equal, second shortest, third and fourth only a little shorter than the first. Hind leg (preserved in specimens No. 3551 and 3553), 4 mm. long, femur thick, tibia slender, all tarsal segments subequal in length.

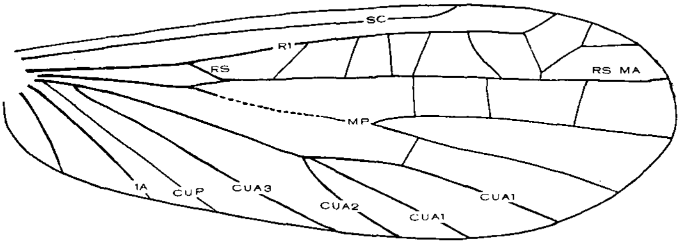

FIGURE 2. *Lisca minuta* Sellards, fore wing, showing extreme condition of coalescence of Rs and MA. Drawn from specimen No. 3568*ab*, Museum of Comparative Zoology.

The holotype of this insect was No. 916 in Dr. Sellards' collection; since that has been lost, I designate specimen No. 3551 in the Museum of Comparative Zoology, as the neotype. This was collected in the upper layer of limestone in 1934 by the writer and consists of a nearly complete insect, showing all four wings outspread, as well as most of the body, including the middle legs, one hind leg, and the cerci.

The species is not so abundant as *typa* in the limestone, but is nevertheless quite common. In the Yale collection there are 47 specimens, in the Sellards' collection 20, and in the Harvard collection 104 specimens. It is equally common in the upper and lower layers of the limestone. Of 42 specimens taken in 1932, when equal areas of the two layers were worked, 18 specimens were found in the lower layer and 24 in the upper. It is interesting to note, however, that the best complete specimens came from the upper layer. The most important of the specimens in the Museum of Comparative Zoology are as follows: No. 3551 (upper layer), consisting of the four wings, legs, cerci, and other body parts, all splendidly preserved; No. 3553ab (upper layer), wings resting back over abdomen, antennae, fore leg and hind leg preserved; No. 3554ab (upper layer), portions of wings and body; No. 3555ab (upper layer), fore and hind wings, general body structure, thorax and cerci excellent; No. 3557ab (lower layer), one very fine fore wing and portions of the thorax and abdomen; 3558ab (lower layer), fore wing and part of the body; No. 3559ab (lower layer) two fore wings, portions of the body; No. 3560ab (lower layer), general body structure, the head, antennae, hind leg and cerci excellent (wings chipped away to expose body); 3561ab (lower layer), excellent fore wing and parts of body; No. 3562ab, fore wing and part of body; No. 3563ab, two fore wings and parts of body. Nos. 3552ab (upper layer) and 3556 (lower layer) are both very fine fore wings. Of the specimens in the Sellards collection two (Nos. 263, 1015) are especially good, since they show both fore wings.

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[6] Tillyard (1928, p. 217) states that the antennae are 3 mm. long and include about 13 segments. The fossil (No. 5210), on which he based this statement, does not appear to show the segmentation of the antennae at all satisfactorily. In two of specimens in the Museum of Comparative Zoology the antennae, also 3 mm. long, consist of 28 or 30 segments, all but the last few being very distinct.

The venation of the fore wing of *minuta* is even more variable than that of *typa*, especially in the amount of fusion between Rs and MA, and Cu and M. In the fore wing of Sellards' original type specimen Rs and MA were coalesced for a short distance, a condition which Tillyard was unable to find duplicated in the Yale collection. He concluded, however, from the presence of a similar condition in some specimens of *typa* that this was a variable feature. That conclusion is borne out by the Harvard material, many specimens (*e. g.* Nos. 3556, 3557) of which show a variable amount of coalescence between Rs and MA. The most extreme case of this sort is in specimen No. 3568 (fig. 2), in which Rs and MA are fused for the entire length of the wing beyond their origins! Although CuA is usually free from M, it is occasionally fused with it at the base, CuA being strongly curved as it leads to the posterior margin. The shape of the fore wing is also liable to vary, some wings being much broader than the others. The coloration is another unstable feature, the wings being uniformly brown in some specimens and banded or colorless in others. Tillyard has given varietal names (such as *semitincta* and *obscurata*) to some of these individual variations, but among the fossils in the Museum of Comparative Zoology there is a complete series of intergradations between the uniformly tinted wings and the colorless ones. He has also described another species, *reducta,* based on a fragment of a fore wing, differing from *minuta* in coloration and the structure of the cubitus, CuA being 2-branched. I do not consider this slight difference in pigmentation as specific, since it merges with other types of coloration in specimens of *minuta;* and the 2-branched condition of CuA occurs as an individual variation in every other species (*cf. typa*) of the Protoperlaria which has thus far been described.[7] I therefore consider *reducta* to be synonymous with *minuta.*

The venation of the hind wing of *minuta* is also variable, especially the amount of fusion between Rs and MA. This is clearly shown in specimen No. 3551 in the Harvard collection, which has Rs and MA coalesced in the left hind wing, but free in the right.

Generally speaking, *minuta* is smaller than *typa,* but this is not always a positive distinction. I have seen some large specimens of *minuta* with the fore wing 7.2 mm. long and some small specimens of *typa* with a fore wing only 5.5 mm. long.

Genus *Artinska* Sellards.

Artinska Sellards, 1909, Amer. Journ. Sci., (4) **26**: 163.
Artinska Tillyard, 1928, Amer. Journ. Sci., (5) **16**: 321.

Fore wing: broad, costal margin arched and apex rounded; Sc terminating well beyond the middle of the wing; R and R1 straight as far as the pterostigmal region, where there is a slight curvature; Rs arising proximad of the middle of the wing, with at least one deep fork and occasionally a small fork on one of the branches; M free from R at the base; MA usually arising slightly proximad of the origin of Rs, either free from Rs or coalesced with it, and being either simple, forked, or 3-branched; MP either simple, 2-branched, or 3-branched; CuA with the characteristic form in the family, with from 2 to 4 branches; CuR unbranched and weakly formed; 1A and 2A present, both very variable in form. *Hind wing:* costal margin arched, apex bluntly rounded, hind margin with a deep incision at the end of CuP; Rl nearly straight throughout; Rs with 2–3 branches; MA coalesced with Rs near the origin of the latter; MA and MP deeply forked; CuA well developed, either fused with M at the base or free.

Body structure: antennae (known only in *clara*) long, multi-seg-

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[7] This 2-branched condition of CuA is of course brought about not by the elimination of CuA3 (= Cu1c), as indicated in Tillyard's figure, but by the coalescence of CuA1 and CuA2 (= Cu1a and Cu1b).

mented, about twice the length of the head and the thorax combined; middle legs short, the hind pair long; cerci longer than the abdomen; hind tarsus (known only in *clara*) with the first segment nearly as long as rest of tarsus.

Genotype: *Artinska clara* Sellards.

This genus, although closely allied to Lemmatophora, is easily distinguished from it by the branched Rs and the longer Sc which parallels the costal margin for most of its length. The antennae, at least in the genotype species, are much longer than those of Lemmatophora, and the prothoracic lobes apparently lack the reticulated pigmentation so obvious in *typa*. The female of both *clara* and *ovata* lacks the prominent dorsal and ventral valves present in the Paraprisciinae.

Artinska clara Sellards.

Figure 3; plate 2, fig. 5.

Artinska clara Sellards, 1909, Amer. Journ. Sci., (4) **26**: 165; fig. 25.
Artinska clara Tillyard, 1928, Amer. Journ. Sci., (5) **16**: 322; fig. 1–7 (full synonymy given here).
Estadia tripunctata Carpenter, 1926, Bull. Mus. Comp. Zool., **77**: 443.

Fore wing: length, 9.5–12.5 mm.; width, 3.5–4.5 mm.; costal margin straight for most of its length, curved only at the base and apically; apex rounded, hind margin curved distally, straight for its proximal half; Sc united with Rs at the very base, but immediately curving anteriorly towards the costal margin, which it parallels until near its termination; 12–18 veinlets between Sc and the margin; R and R1 straight, without the bend at the origin of Rs, curved only in the

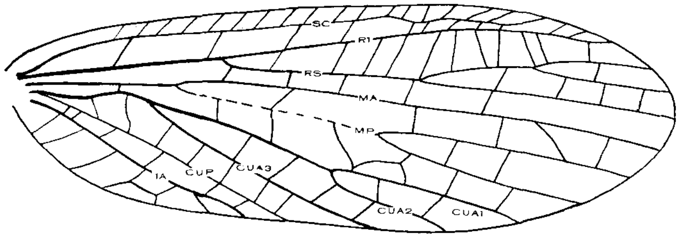

FIGURE 3. *Artinska clara* Sellards, fore wing, drawn from specimen No. 3568*ab*, Museum of Comparative Zoology.

pterostigmal region; Rs arising proximad of the middle of the wing, deeply forked and occasionally 3-branched; between Rs and R1 8–13 cross-veins; M nearly straight at the base, forking into MA and MP just proximad of the origin of Rs; MA frequently coalesced with Rs for a variable distance; CuA a very strong vein, and the numerous cross-veins between its branches are also heavy; CuP very weak, but connected with CuA and 1A by strong cross-veins.

Hind wing: length, 8.5–11.5 mm.; costal margin somewhat variable in shape, in some specimens nearly straight, in others arched; Sc close to the wing margin at the base, curving towards R and remaining closer to R than to the margin for the rest of its length; R1 very nearly straight, even in the apical region; Rs arising close to the base of the wing, coalescing for a short distance with MA and forming three terminal branches; MA forked in all specimens which I have seen; MP deeply forked to a point more proximad than the middle of the wing; CuA fused with the stem of M at the base of the wing and deeply forked to more than half its length.

Body structure: length of body, including cerci, 15 mm.; antennae 10 mm. long, about twice as long as the head and thorax combined, the first few segments short and broad, the next few about twice as long as wide, the others a little longer than broad; prothorax lobes fully as large as those of *typa*, extending even further back over the mesothorax than in that species, but completely lacking the pigmented net-work; fore legs not preserved in any specimens; middle legs short, femur 2.2 mm. long; hind leg long, femur 3 mm. long; tibia slender, 3.5–3.8 mm. long; tarsi 2.7 mm. long, the first segment nearly as long as the rest of the tarsus, the second segment equal to the combined third and fourth segments, which are equal; and the fifth equal to the second; cerci 6 mm. long, stout.

The holotype specimen of this species was No. 115 in the Sellards collection. Since that fossil has been lost, I designate as neotype specimen No. 3568ab in the Museum of Comparative Zoology; this was collected by the writer in 1932 in the lower layer of limestone and consists of a complete and splendidly preserved fore wing.

Clara is another common species in the Elmo limestone, there being 64 specimens of it in the Yale collection, 10 in the Sellards collection and 160 in the Harvard material. It is not so abundant in the upper layer of limestone as in the lower; of 64 specimens collected in 1932, when equal areas of the two layers were worked, only 21 were found in the upper layer, whereas 43 were taken in the lower. The following specimens, all from the lower layer, are the most important ones in the Harvard collection: Nos. 3565ab, fore wing, portions of body, head, prothorax, hind and middle legs, cerci; No. 3566ab, fore wing, parts of hind wings, hind leg and cerci; No. 3567ab, two fore wings and parts of hind wing, general body structure only; 3600, both fore wings and parts of body, including head and both antennae (excellent); Nos. 3568ab, 3569ab, 3570ab, 3571ab, all fore wings, splendidly preserved.

The wing venation of this species is exceedingly variable, much more so than in *typa*. As already indicated by Tillyard, the radial sector may be either two- or three-branched; the anterior media either unbranched, two-branched or three-branched; MP either two-branched or three-branched; and CuA either two-, three-, or four-branched. In the accompanying table I have indicated the percentage of specimens in the 160 fossils in the Museum of Comparative Zoology with the various types of venation. In addition to these variations, the degree of coalescence of Rs and MA and between CuA and M is likewise unstable; in 88% of the Harvard specimens Rs and MA are free from each other, though in the remainder they are coalesced to a greater or less extent; in some they coalesce twice, the veins separating for a short space, only to join again further along. In 87% of the specimens Cu and M are free, but in the rest they are fused.

TABLE I.

DISTRIBUTION OF VENATIONAL VARIATIONS IN *A. clara*.

The figures indicate the percentage of specimens in each category.

	Rs	MA	MP	CuA
unbranched		60%		
two terminal branches	80%	26%	89%	3%
three terminal branches	20%	4%	11%	84%
four terminal branches				13%

The general habitus of this insect is similar to that of *typa*, but there are certain features of the body which are very different. The most interesting of these is in the antennae, which are perfectly preserved in one specimen (No. 3600) in the Harvard collection. They are much longer than the body and contain upwards of 110 segments, each of which bears a pair of hairs projecting anteriorly. The proximal few segments are very broad and short; the next 6 segments are about as long as broad; and the remainder are not much longer than broad. The most remarkable feature about these antennae, in addition to their large number of segments, is the presence of an enlarged segment at regular intervals of 6 segments throughout the middle portion of the antennae. Fortunately, in the specimen mentioned both antennae are preserved and are parallel and close together, as shown in the photograph (figure 5, plate 2), so that it is possible to observe the exact correspondence of the enlarged segments in each antenna. When the fossil is examined under low power magnification, this series of enlarged segments gives the impression that in the middle portion of the antennae the segments are long and slender, since the smaller segments are not distinguishable; under high power, however, the true segmentation can be easily seen. So far as I am aware, there is nothing comparable with this condition among existing insects. It seems probable, however, that these enlarged segments were the seat of special sense organs. It is also possible that the antennae of this fossil illustrates one type of reduction in the number of segments in the insects as a whole, the joints between the small segments included in the interval between the large ones gradually disappearing.

Artinska ovata Sellards.

Figure 4.

Orta ovata Sellards, 1909, Amer. Journ. Sci., (4) **26**: 168; fig. 23.
Artinska ovata Tillyard, 1928, Amer. Journ. Sci. (5) **16**: 331; fig. 9–12.

Fore wing: length 6.5–8.5 mm.; width, 2–3 mm. Costal margin uniformly curved, apex somewhat more pointed than in *clara;* hind margin nearly straight; Sc close to R at base, straight for its entire length; 8–12 veinlets between Sc and margin; R straight at base, but curved anteriorly at the origin of Rs and usually curved posteriorly in the pterostigmal region; Rs arising proximad of the middle of the

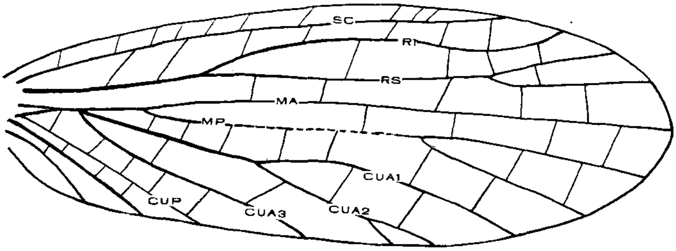

FIGURE 4. *Artinska ovata* Sellards, fore wing, drawn from specimen No. 3602*ab*, Museum of Comparative Zoology.

wing; deeply forked and occasionally 3-branched; 6–8 cross-veins between R and Rl; MA arising at about the level of the origin of Rs, not coalesced with Rs in any specimen studied thus far; MA usually simple, occasionally twigged; MP deeply forked; CuA frequently coalesced with M for a short distance. The fore wing is usually brownish in color, which is apparently due to a uniform pigmentation, although some wings are mottled with brown patches on a colorless membrane.. The pattern formed in the latter case is not alike in any two specimens. *Hind wing* unknown.

Body structure: length of body, including cerci, 10 mm.; prothoracic lobes large, proportionally as large as those in *clara.* Fore legs short, 2 mm. long, the tibia 1 mm. long and the tarsus .7 mm. long (specimen No. 3575); middle legs unknown; hind legs (specimen No. 3575) long, 2 tibial spurs present, femur 1.8 mm. long, stout; tibia 2 mm. long, slender; tarsus unknown; only the 6 proximal segments of the antennae are known; these are broad, as long as wide and bear a pair of projecting spines distally, as in *clara* (specimen No. 3576).

The holotype of this species was No. 295 in the Sellards collection. Since that has been lost, I designate as the neotype specimen No. 3575ab in the Museum of Comparative Zoology; this was collected by the writer in the lower layer of limestone in 1932 and consists of a whole insect, showing especially well a fore wing, the prothoracic lobes, both front legs, and one hind leg (tarsus missing).

Ovata is similar to *clara* in most respects, but it is usually smaller, Sc of the fore wing is straight proximally (not arched as in *clara*) Rl is bent at the origin of Rs, and Rs is free from MA (in all specimens which have thus far been studied). The body structure seems to be very similar to that of *clara,* but unfortunately not much of it is known. Only a few segments of the antennae have been preserved and they are not sufficient to show whether or not the segmentation was like that in *clara.*

The species occurs commonly in the limestone, there being 30 specimens in the Yale collection and 76 in the Harvard material; it is rare, however, in the upper layer of limestone, for out of 21 specimens found in 1932, only one came from the upper layer. The following, all from the lower layer of limestone, are the most important specimens in the Harvard collection: No. 3573ab and 3601ab. complete and very well preserved fore wings; No. 3755ab, the neotype: No. 3576ab, a complete insect, showing the head, thorax, part of the antennae, and the four wings, though the venation in the hind wings is so faint that the veins cannot be followed. The latter specimen and the neotype are the first specimens found which show any portion of the body of this species.

Although most specimens of *ovata* are much smaller than *clara*, the average length of the fore wing being around 6.5 mm., some individuals have a wing length of 8.5 mm., which is very nearly the size of small specimens of *clara*. The venation is somewhat more stable than that of other Lemmatophoridae. It is the only species of the family represented by numerous specimens in which Rs and MA are always free. In other respects, however, the venation is very variable. One specimen (No. 3602ab, lower layer) in the Museum of Comparative Zoology has a curious formation of Rl which I have not encountered in any other specimens of Protoperlaria; after the origin of Rs it arches anteriorly close to the subcosta, and then almost beneath the pterostigma, it diverges posteriorly until it almost touches Rs, finally bending anteriorly again and terminating as usual (Figure 4). Since this is the only specimen showing such a conformation, I consider it to be only an abnormal individual, rather than a representative of a new species or form.

Artinska sellardsi Tillyard.

Artinska sellardsi Tillyard, 1928, Amer. Journ. Sci. (5) **16**: 330.

Fore wing: length, 10.5–12 mm.; width, 3.6–4 mm.; costal margin curved, apex pointed; Sc united with R at the very base, straight for its entire length; R straight at the base, but bent upwards at the origin of Rs, as in *ovata;* Rs forked to about half its length; MA arising at about the level of the origin of Rs; CuA with 3 or 4 branches, either fused with M at the base or entirely free; CuP weak; anal veins unknown; cross-veins arranged as in *ovata*, though perhaps weaker.

Holotype: No. 5291a in the Yale collection, Peabody Museum, and its counterpart in the Cawthron Institute in New Zealand.

This insect differs from *ovata* only by its larger size and will perhaps turn out to be synonymous with that species. In the collection at the Museum of Comparative Zoology there is one specimen (No. 3603) which agrees in all respects with the type, except for minor individual details, such as the extra fork on R2 + 3 and CuA2. It was collected in the lower layer of the limestone in 1927 and is complete except for part of the anal area.

Subfamily PARAPRISCINAE.

Genus *Paraprisca* Handlirsch.

Prisca Sellards, 1909, Amer. Journ. Sci. (4) **26**: 167 (*nec* Prisca Fritsch, 1899).
Paraprisca Handlirsch, 1919, Denkschr. Akad.-Wiss. Wien, **96**: 45.
Paraprisca Tillyard, 1928, Amer. Journ. Sci., (5) **16**: 334.

Fore wing: narrow, costal margin curved, apex acutely rounded; Sc close to margin and parallel to it for its entire length; R straight with no curve at origin of Rs, nor at the pterostigmal region; Rs either simple or forked; MA usually unbranched, rarely forked, arising proximad of the middle of the wing; MP forked, rarely 3-branched; CuA not coalesced with M at any one point; CuP very weakly chitinized. *Hind wing:* slender; apex pointed, hind margin with a slight incision only, at the termination of CuP; Sc long, terminating near the apex; Rl straight in pterostigmal region; Rs unbranched (in all specimens studied), originating near the base of the wing; MA unbranched, MP forked; first branch of 2A deeply forked.

Body structure: antennae long, nearly twice as long as the head and thorax combined; prothoracic lobes small; all legs slender, the hind pair being exceedingly tenuate; first segments of hind tarsus as long as the others combined; cerci short. Female with dorsal and ventral valves visible externally.

The genotype of Paraprisca is *Prisca fragilis* Sellards, which until now has been the only known species of the genus. In the Harvard collection there are two specimens belonging to a second species, readily distinguished by its much larger size.

Paraprisca fragilis (Sellards).

Figure 5.

Prisca fragilis Sellards, 1909, Amer. Journ. Sci., (4) **26**: 167; fig. 22.
Paraprisca fragilis Tillyard, 1928, Amer. Journ. Sci., (5) **16**: 336; fig. 13–15.

Fore wing: length, 9–10.5 mm.; width, 2.3–3.2 mm.; Sc parallel to R for nearly its entire length, terminating near the apex; costal space with a few weak veinlets visible only in perfectly preserved specimens; R close to Sc at the base, but diverging away slightly after a short distance; Rs arising slightly proximad of the middle of the wing, either free from MA or coalesced with it; 3–5 cross-veins between Rs and MA; MA arising well proximad of the origin of Rs and unbranched in all specimens which have been examined; 3–6 cross-veins between MA and MP; MP always deeply forked, nearly to the middle of the wing, occasionally with a short third branch; 5–8 cross-veins between MP and CuA; CuA close to M as far as the origin of CuA3, then curving posteriorly; usually two cross-veins between CuA1 and CuA2, and four between CuA3 and CuA2; CuA with the three branches characteristic of the family, CuA1 terminating at about the beginning of the distal third of the wing; CuA2 terminating before the middle of

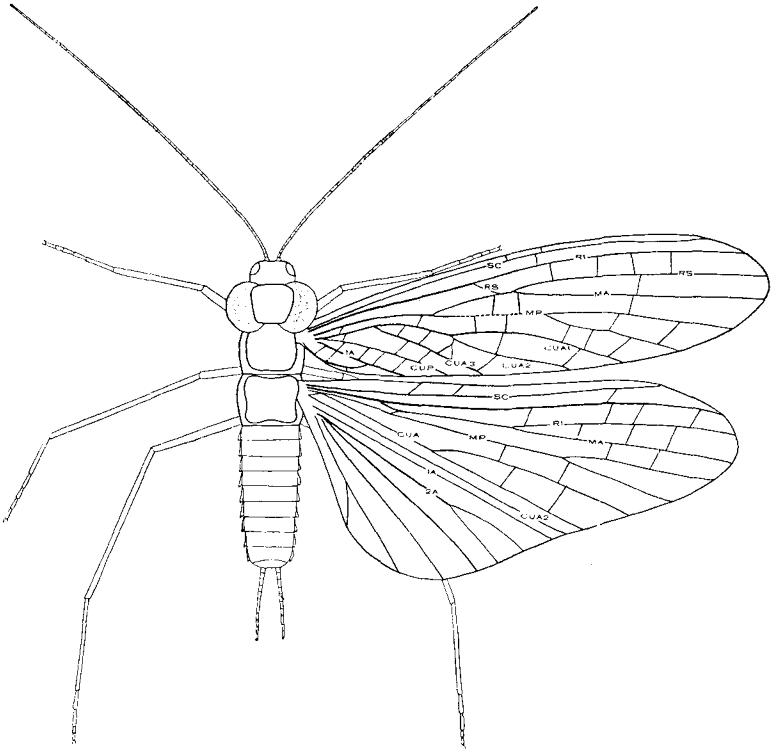

FIGURE 5. Reconstruction of *Paraprisca fragilis* (Sellards), based on specimens No. 3582*ab* and 3599*ab*, Museum of Comparative Zoology. The segments of the fore and middle tarsi are unknown; they are restored here on the basis of the segmentation in the hind tarsus (see text).

the wing; 3–4 cross-veins between CuP and 1A and 3 between 1A and 2A; 1A short variably formed; 2A very close to inner margin of wing. *Hind wing:* length 8–9 mm.; costal margin concave near mid-point; Sc is approximately mid-way between the costal margin and Rl; Rl slightly concave; Rs coalesced with MA for a short distance; CuA1 forked to mid-wing; 2A with a shallow fork.

Body structure: length of body, 5 mm. (specimen No. 3579ab); antennae 6 mm. long, the segments near the middle about three times as long as broad, those near the base of the antennae not preserved; fore leg, 3.5 mm. long, segmentation of tarsus not clear (specimen No. 3582ab); middle leg, 5 mm. long, tarsal segmentation not clear; hind leg, 6.5 mm. long, first tarsal segment very long, second and third each about one-fourth the length of the first, fourth and fifth each one-half the length of the third; cerci 1.5 mm. long.

The holotype of this species was No. 128 in the Sellards collection; since that has been lost, I designate as the neotype specimen No. 3582ab, collected by the writer in the lower layer of limestone in 1927. This specimen is nearly complete, showing the fore and hind wings out-spread, and the antennae, legs and cerci.

Fragilis is not a common species in the Elmo limestone, although there are 13 specimens in the Yale collection, 2 in the Sellards, and 36 in the Museum of Comparative Zoology. All of these fossils have been found in the lower layer of the limestone, which would indicate that the species is absent or at least very rare in the upper layer. The following are the most important specimens in the Harvard collection: No. 3582ab, the neotype, mentioned above; No. 3581ab, 3580ab, 3604ab, and 3605ab, all fine and complete fore wings; and No. 3599ab, a nearly complete insect, showing the abdominal structures especially well.

The long antennae and tenuate legs make *fragilis* the most striking of all Protoperlaria which have been found thus far. Unfortunately, the body structure is not so well known as that of Lecorium or most other members of the family Lemmatophoridae. I have attempted (figure 5) to reconstruct a figure of this insect, based upon all specimens which have been collected, in order to show the unusual habitus of the species. It has not been possible, however, for me to make out the structure of the fore and middle tarsi, or the segmentation of the antennae as a whole, since they are not preserved sufficiently well in any of the fossils; and the shape of the thoracic *nota* is likewise unknown. The other body features shown in the figure,—the long antennae, small prothoracic lobes, long legs, and the segmentation of the hind tarsus, and short cerci,—are all definitely indicated in the fossils at hand.

The venation of the fore wing is apparently as unstable as that of other members of the family, Rs being either free or coalesced with MA, MP having either two or three branches, etc. In *fragilis,* however, as well as in *Lecorium elongatum,* the branching of Rs is subject to variation in that it may be either simple or forked.[8] CuA, although it sometimes has two as well as three branches, is apparently never coalesced with M; at least, it is not so formed in any of the 51 specimens which have been studied. Since CuA is a very strong vein, and usually well preserved, this free condition provides an easy means of recognizing the genus Paraprisca.

Paraprisca grandis, new species.

Figure 6.

Fore wing: length, 17–18 mm.; width, 4.5 mm. Sc terminating at the beginning of the pterostigma; costal space with only one or two veinlets near the middle of the wing; R nearly in contact with Sc at the base; Rs arising proximad of the middle of the wing and free from MA in the type specimens; 9–12 cross-veins between Sc and Rl; 10 between Rl and Rs; Rs forked (in types); 8 cross-veins between Rs and MA; MA and MP diverging proximad of the origin of Rs; MA either forked or simple; MP forked to about the middle of the wing; 8 cross-veins between MA and MP and between CuA and MP; CuA1 is straight and not forked until near the wing margin; CuA1a forks a short distance beyond its origin (in the types); CuA2 very straight;

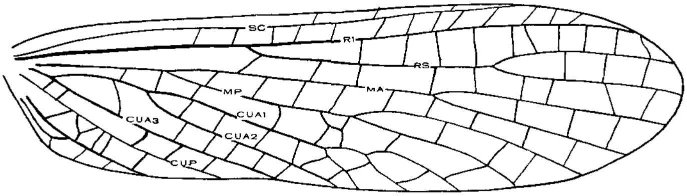

FIGURE 6. *Paraprisca grandis,* n. sp., fore wing; holotype, No. 3585*ab,* Museum of Comparative Zoology.

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[8] This variation has much significance, since, as I shall show below, Tillyard erected the genus Sellardsia and two species upon specimens of *Lecorium elongatum* which had a forked Rs.

CuP smoothly curved; 1A very strong, nearly parallel to CuP; 2A well developed, remote from the inner margin of the wing; color of wing, uniformly light brown, due mainly to the covering of brown microtrichia.

Holotype: No. 3585ab, and paratype No. 3584ab, both collected by the writer in the lower layer of limestone in 1927, and both consisting of a complete and well preserved fore wing.

This species is close to the genotype, but can easily be distinguished by its much larger size, the fore wing being about twice as long as that of *fragilis*. It is the largest species of the order Protoperlaria which has been found. There are several venational differences between *fragilis* and *grandis*, such as the more uniform width of the wing, the shorter Sc, and the small fork on CuA1.

Genus *Lecorium* Sellards.

Lecorium Sellards, 1909, Amer. Journ. Sci., (4) **26**: 167.
Stemma Sellards, *ibid.*, p. 168.
Lecorium Tillyard, 1928, Amer. Journ. Sci., (5) **16**: 340.
Sellardsia Tillyard, 1928, *ibid.*, p. 343.

Fore wing: narrow; costal margin nearly straight, apex rounded; Sc remote from margin at base, gradually approaching it towards the middle of the wing, after which it runs parallel to the margin; R curved posteriorly slightly just before or at the origin of Rs and again in the region of the pterostigma; Rs either forked or unbranched; MA nearly always unbranched, either free from Rs or coalesced with it; MP forked, frequently 3-branched; CuA always coalesced with M, usually just before or at the separation of CuA1 and CuA2; CuA1 either simple or branched; CuP very weakly chitinized; 1A simple; cross-veins well developed, especially those in contact with CuP. *Hind wing:* slender, apex pointed; hind margin with a very slight indentation at the termination of CuP; Sc long, terminating near the apex; R1 nearly straight; Rs either unbranched or forked, originating near the base of the wing; MA unbranched, usually coalesced with Rs; MP forked; first branch of 2A deeply forked.

Body structure: antennae about as long as the head and thorax combined; prothoraici lobes larger than in Paraprisca, but not so large as in Lemmatophora; all legs stout, the hind pair long, but robust; first segment of hind tarsus as long as the others combined; cerci as long as the abdomen; female with external dorsal and ventral valves.

Genotype: *Lecorium elongatum* Sellards.

Lecorium elongatum Sellards.

Figures 7, 8, 9; plate 1, fig. 2.

Lecorium elongatum Sellards, 1909, Amer. Journ. Sci., (4) **26:** 167; fig. 26

Stemma elegans Sellards, 1909, *ibid.*, p. 168; fig. 27.

Stemma extensa Sellards, 1909, *ibid.*, p. 168.

Lecorium elongatum Tillyard, 1928, Amer. Journ. Sci., (5) **16:** 341; fig. 16–18.

Sellardsia kansasensis Tillyard, 1928, *ibid.*, p. 349; fig. 19–20.

Sellardsia lecoriodes Tillyard, 1928, *ibid.*, p. 345; fig. 22.

Fore wing: length, 7–9 mm.; width, 2–2.7 mm.; Sc not parallel with Rl; costal space with from 5–12 well developed veinlets; R close to

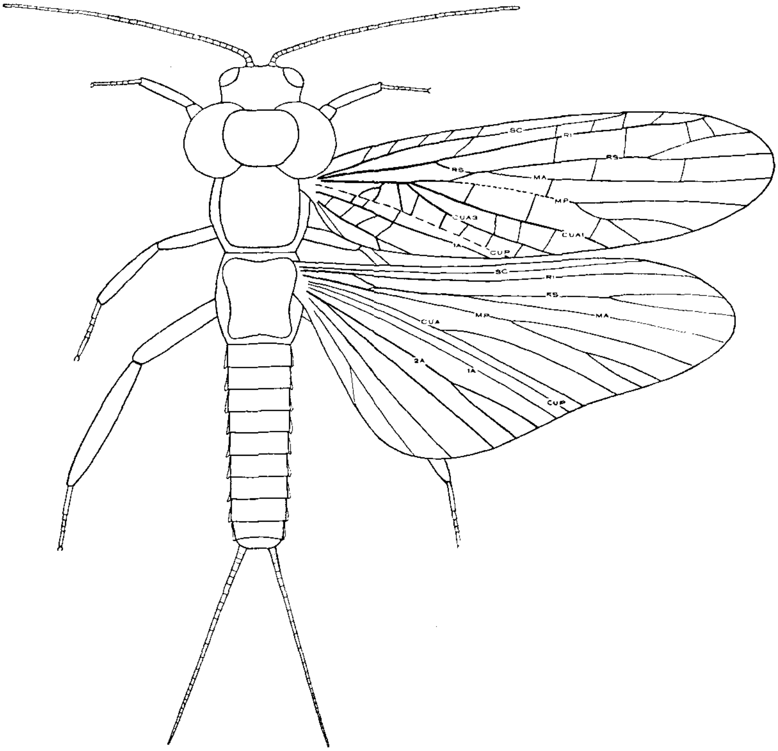

FIGURE 7. Reconstruction of *Lecorium elongatum* Sellards, based on specimens No. 3595*ab*, 3607*ab*, 3587*ab*, 3594*ab*, 3590*ab*, Museum of Comparative Zoology.

Sc at the base of the wing and also in the pterostigmal region; Rs arising proximad of the middle of the wing; 4–7 cross-veins between R1 and Sc, and 5 or more between Rs and MA; MA arising at about the same level as Rs or somewhat more distad of that point; 2–4 cross-veins between MA and MP; MP deeply forked, frequently with an extra fork on either MP1 or MP2; the amount of fusion between CuA and M is very variable, even in right and left wings of the same individual (see figure 8); 3–4 cross-veins between CuA1 and MP, and 3 between CuA1 and CuA2, and 6–8 between CuA2 and CuP; 2A is either simple or twigged. *Hind wing:* length, 6–8 mm.; costal margin concave over the middle part of the wing; Sc approximately mid-way between the anterior margin and R1; R1 very slightly concave; Rs either unbranched or forked, either coalesced with MA or free from it; MP forked nearly to mid-wing; inner angle of wing bluntly rounded.

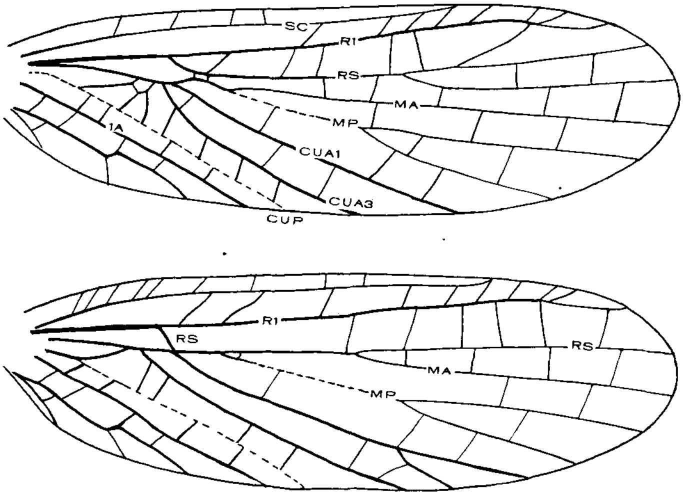

FIGURE 8. *Lecorium elongatum* Sellards; right and left fore wings of specimen No. 3587*ab*, showing differences in venation.

Body structure: length of body (not including antennae) 13.5 mm.; antennae 5 mm. long, the first ten segments about as broad as long, the others about twice as long as broad; length of head, 1 mm.; prothorax, 1.2 mm.; mesothorax, 1.7 mm.; metathorax, 1.8 mm.; prothoracic lobes uniformly pigmented without the network found in *Lemmatophora typa;* fore legs short and stout, tibia 1 mm. long; tarsus .9 mm. long, the fifth segment the longest, the first about one-half the length of the fifth; the second, third and fourth only one-half the length of the first; middle legs twice as long as the fore, robust, femur 2 mm. long, tibia 1.8 mm. long, tarsus, 1.4 mm. long, segmentation similar to that of the fore leg; hind leg long, robust, femur 2.3 mm. long, tibia 2.7 mm. long and somewhat swollen at the middle, narrowed distally; tarsus 1.5 mm. long, the first segment a little longer than the fifth, the second, third and fourth very short. Abdomen slender, 4 mm. long; cerci 4 mm. long, very slender distally, with about 31 segments, the first 3 being very short, the next ten much longer than broad, the remainder about as broad as long.

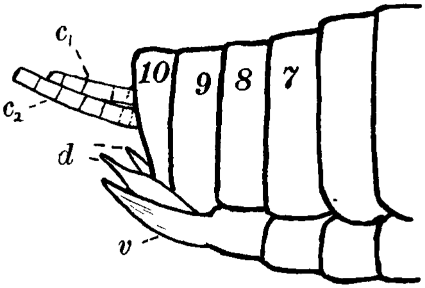

FIGURE 9. *Lecorium elongatum* Sellards; diagram of distal part of abdomen, drawn from specimen No. 3591*ab*, Museum of Comparative Zoology. c_1, left cercus; c_2, right cercus; *d*, dorsal valve; *v*, ventral valve.

The holotype of this species was No. 524 in the Sellards collection; since that has been lost, I designate as the neotype specimen No. 3587ab in the Museum of Comparative Zoology; this was collected by the writer in the lower layer of the limestone in 1927 and consists of a nearly complete specimen, with the fore wings, parts of the hind wings, the antennae, thorax, abdomen, both fore legs, one middle leg, one hind leg and the cerci.

In the Yale collection there are 16 specimens of this species; in the Sellards collection 4 specimens (Nos. 441, 1272, 927, 54), all fore wings; and in the Harvard collection 46 specimens, all from the lower layer of limestone. The following are the most important of the fossils in the Harvard collection: Nos. 3597ab, 3596ab, 3598ab, 3583ab, 3592ab, 3588ab, 3606ab, all fore wings, splendidly preserved; Nos. 3595ab, a lateral view of the whole insect, the cerci and the wings especially good; No. 3607ab, lateral view of the insect, the abdomen and cerci particularly good; 3591ab, lateral view of the complete insect, showing thorax and abdomen especially well; No. 3589ab, a dorsal view, the antennae, thoracic lobes, cerci, abdomen, fore leg and hind leg, all very well preserved; No. 3587ab, the neotype, described above; No. 3594ab, dorsal view, head, basal part of antennae and hind wing; No. 3590ab, a dorsal view of the insect, the base of the antennae, one hind leg, the cerci and the abdomen being especially good.

The wing venation of this species is more variable than that of any other Protoperlarian. The large series of well preserved specimens in the Harvard collection, added to those previously studied, has enabled us to determine more satisfactorily than before the extent of this variability. Not realizing the degree of this instability, Tillyard erected the genus Sellardsia for two new species, *kansasensis* and *lecoriodes*. He defined the genus Sellardsia simply by the statement that it differed from Lecorium only by having Rs strongly forked instead of simple. But there are several specimens in the Harvard collection possessing both of the fore wings, in one of which Rs is strongly forked but unbranched in the other (fig. 8). There can be no doubt therefore of the synonymy of Sellardsia with Lecorium. *Kansasensis,* the genotype of Sellardsia, thus becomes a very typical *elongatum,* for aside from the forked Rs it fits perfectly into even Tillyard's conception of the latter species. *S. lecoriodes* was separated from *Kansasensis* by having the apex more rounded, the origins of Rs and of the branches of CuA further apart, and 1A not quite so close to CuP; it was distinguished from *Lecorium elongatum* by having a short Rl and a more distal origin of Rs. All of these are minor venational features, which, as shown by the study of the Harvard material, differ in the right and left wings of the same specimen.

The amount of fusion between Rs and MA in the fore wing is even more variable than in Paraprisca; in some specimens the two veins are very remote from each other, whereas in others they are fused together almost to the very apex of the wing (specimen No. 3608). Specimens with these veins fused only slightly predominate, 60% of the fossils in the Harvard collection falling in this class. MA is nearly always simple, only two specimens in the Harvard collection having this vein forked. MP is two-branched in more than one-half of the specimens. The following table summarizes the data on the variation of the branching of the veins in the Harvard specimens of *elongatum:*

TABLE II.

Distribution of venational variations in *L. elongatum.*

	Rs	MA	MP	CuA
unbranched	77%	93%	7%	
two terminal branches	18%	7%	53%	38%
three terminal branches	5%		40%	62%

The branching of CuA was in part misinterpreted by Tillyard. Observing that of the five specimens of *elongatum* in the Yale collection which possessed only a two-branched CuA, all had a three-branched MP, he concluded that the first branch of CuA (*i. e.* CuA1) had switched anteriorly and fused with MP for a very short distance, so that it now appears to be a third branch of the latter. However, in all the other common species of Lemmatophoridae (*L. typa, L. minuta, A. clara, A. ovata, P. fragilis*) a two-branched CuA and a two-branch MP sometimes occur simultaneously, a condition which in itself throws much doubt on the conclusion that MP had acquired a branch of CuA in *elongatum.* Furthermore, in the Harvard collection of the latter species, there are ten specimens which possess a two-branched CuA, and of these seven have a two-branched MP, whereas only three have a three-branched MP. If we add to this number the five fossils in the Yale collection possessing a two-branched CuA, we find that out of a total of 15 specimens possessing a two-branched CuA, 8 have a three-branched MP, and 7 have a two-branched MP. This of course is a very close approach to the equal ratio which would be expected if the loss of the branch of CuA and the addition of the third branch of MP were not correlated and their simultaneous occurrence a matter of chance.

Since no portion of the body of Lecorium has previously been known, the specimens in the collection at the Museum of Comparative Zoology have greatly advanced our knowledge of this insect and of the Protoperlaria in general. Although the wings are closer to those of Paraprisca, the body structure is much nearer to that of Lemmatophora, as indicated by the length of the antennae and cerci, as well as by the build of the leg and the tarsal structure. The formation of the prothoracic lobes is shown better in one specimen of *L. elongatum* in the Harvard collection than in any other fossil belonging to the order which has been studied. This specimen (No. 3591ab) shows the insect in a lateral view, and although the thorax is somewhat crushed, the lobes can distinctly be seen to arise from beneath the pronotum rather than to be attached to the upper surface of the pronotum.

It was stated above that the females of Paraprisca and Lecorium possessed external dorsal and ventral valves. This assertion was based upon the interpretation of two paired processes visible in several specimens of these genera in the Museum of Comparative Zoology, and best preserved in specimen No. 3591ab (Lecorium). The chief difficulty attending the interpretation of these structures is in the determination of the sex of the insect represented. Since, however, there are no processes present in the males of the Recent Perlaria or related Orthopteroids with which we can homologize those in the fossils, I believe it most probable that the latter (at least specimen No. 3591) are females. In the photograph shown in figure 2 plate 1, I have labeled the several terminal structures on the abdomen and in figure 9 have presented a drawing of the same specimen which makes somewhat clearer than the photograph the position of attachment of these processes.[9] It will be seen that portions of both cerci are preserved in the specimen, as an examination of the obverse and reverse of the fossil immediately reveals. In the obverse (which is the half shown in the photograph) the basal and distal portions of the left cercus and a section near the middle of the right cercus are preserved. Below the cerci and apparently arising from the 9th abdominal segment are two short, paired processes, the one on the right side being partially obscured at the base by the one on the left. Further ventral are two other paired structures, the right one almost entirely hidden by the left, only the tip being visible; these appear to originate from the 8th sternum.

If we now turn to the Recent Perlaria for homologous structures, we find that, as pointed out by Walker (1919) in some species (as *Megarcys signata* Hagen) the 8th abdominal sternum is frequently bilobed posteriorly, the lobes being suggestive of vestigial ventral valves. In Pteronarcys, also, though there is no backward extension of the 8th stermum as a whole, there is a pair of slender processes near the hind margin of the segment which are considered by Walker to be true representatives of the ventral valves. It seems very probable, therefore, that the lower paired processes in the specimen of Lecorium are reduced ventral valves, not so markedly diminished in size, however, as those in Pteronarcys and other Recent Perlarians. The upper paired processes (apparently arising from the 9th sternum) are not so easily explained, for in none of the existing Perlaria are there any indications of similar structures. They resemble very closely in shape the paraprocts which are well developed in many recent stone-flies (*e. g.* Pteronarcys), but in the fossil they are much too ventral to be paraprocts, unless we assume that distortion in the fossil has caused some misplacement; no such distortion, however, is suggested in the rest of the fossil. But their position is exactly that which would be held by dorsal valves, if they were present; and since the ventral valves appear to be much larger than in the existing Perlarians, it is not hard to believe that the dorsal valves were also well developed. My present interpretation of these two pairs of processes, therefore, is that the lower ones are free ventral valves, somewhat less reduced than those in Recent Perlarians; and that the upper ones are vestigial dorsal valves, which though not present in the Perlarians, are well developed in certain other groups of the Orthopteroidea, including the Protorthoptera.

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[9] I am indebted to Professor G. C. Crampton for helpful suggestions concerning the interpretation of these processes.

The Nymphs of the Protoperlaria.

In the discussion of the ordinal characteristics of the Protoperlaria given above, it was stated that the immature stages of these insects were aquatic, and that many nymphs belonging to the order were found in the limestone with the adults. Since, however, it is not possible to correlate these nymphs specifically with the adults, I have considered it advisable to treat the nymphal forms together without attempting to place them in any of the foregoing genera.

In the collection at the Museum of Comparative Zoology there are in all 82 specimens of nymphs which belong, in my opinion, to the Protoperlaria. Of these, all but 6 inferior specimens were taken in the upper layer of the limestone, a fact which undoubtedly accounts for their apparent absence in the Yale collection, which was secured in the lower layer of the limestone.

The first question which naturally arises in connection with these immature specimens is how we are able to associate the nymphs even with the Protoperlaria, since we are obviously unable to use the rearing methods employed in dealing with the immature stages of recent insects. I believe, however, that we can cover this point definitely by the process of elimination and by a comparison of the fossil nymphs with those of the existing Perlarians.

Among the insects which occur in the Elmo limestone there are four orders which, because of their affinities with certain Recent groups, lead us to believe that they were aquatic in the nymphal stages: the Protodonata, Odonata, Plectoptera and Protoperlaria. No nymphs of the Protodonata have ever been found in any formation, but they would certainly be at once recognized by their large size and Odonate facies. The Odonata are extremely rare in the Elmo limestone, only a half dozen insects having been found, and these are so distinctly Odonate in character that the nymphs must have been very similar to those of the Recent Odonata. The Plectoptera are common in the limestone, and because of the variety of nymphal types in the order, it is not easy to draw sharp lines between the nymphs of the Recent Plectoptera and the Perlaria, at least on such general characteristics as are preserved in the fossils. However, if we compare all available details of the fossil nymphs with those of the may-fly nymphs, it will be apparent that there are many discrepancies. The terminal abdominal appendages, for example, are characteristic nymphal cerci, short and thick, quite unlike the slender caudal filaments of the may-fly nymphs; and the broad flattened body of the fossils is very different from the slender tapering one of the may-flies. Most important of all in this connection, perhaps, is the fact that nymphs, very much like those of Recent may-flies, even in smallest details have been found in the Permian of Russia (Kargala). But when we compare the Kansan Permian nymphs with those of Recent Perlarians, we find at once such similarity that it is difficult to detect the differences which we might expect in view of the great age of the fossils. The similarities will be considered below, but it should be noted here also that the great abundance of adults of the Protoperlaria (more than 800 specimens having been collected in the limestone) is another point in favor of the conclusion that the nymphs are the immature stages of the members of that order.

In attempting to sort the eighty-two specimens of nymphs into species, we are greatly handicapped by the absence of wings, which are the principal taxonomic tool in dealing with fossil insects. Since no two specimens of the nymphs are preserved in exactly the same attitude, it is a very difficult matter to find characteristics which enable us to segregate related specimens in groups. Under such circumstances one is tempted to fall back upon size as a convenient means of correlating specimens, and although of course the size of the nymphs differs in the various instars, this procedure seems to work with some degree of satisfaction in the case of the Protoperlarian nymphs. Of the total of eighty-two nymphs, 38 are 9–10 mm. long (group A) and 41 are 4.8–5.5 mm. long (group B), only three specimens in the entire lot having an intermediate length of 7 mm. Although in all probability some of the smaller nymphs in group B are in reality young nymphs of the species represented in group A, I believe that on the whole group B consists mainly of the nymphs of either *Lisca minuta* or *Artinska ovata,* or both; while group A consists mainly of the nymphs of either *L. typa, A. clara, P. fragilis,* or *L. elongatum,* or of all four species. In each group there are about 6 or 7 specimens which are complete and sufficiently well preserved in dorsal view to enable comparison; since I can find no structural differences between most of the well preserved fossils in their respective groups, I consider it probable that the small nymphs are chiefly one species and the large nymphs mostly one species, though it is apparently impossible to associate these with any of the species represented by the adults. I propose, therefore, to describe the best specimens in the above groups, without attempting to place them in any of the known genera.

Of the series of larger nymphs (group A) the best specimen by far is No. 3622, collected by Ruth F. Carpenter in the upper layer of limestone in 1932. This is a complete insect and is splendidly preserved. The body, which is 14 mm. long, including the cerci, is shown in dorsal aspect, but the legs, of which five are preserved, are turned in such a manner that they are seen in lateral view. This condition, which is shown in the drawing of the specimen (figure 10), gives the insect a slightly distorted appearance, but probably enables us to see more of the leg structure than would otherwise be possible. The antennae, which are 2.8 mm. long, contain 13 segments, the first being very short and broad, the next three being about as long as broad, and the rest about two and one-half to three times as long as broad. The antennae are rather broad at the base, but very slender distally. The head is rounded in front and as preserved in this fossil is two and one-half times as wide as long, although since the head is apparently bent downwards as in most adults, the true length of the head is probably much greater than it is indicated in the fossil. The eyes are well preserved in the specimen, one being distinct in the obverse and the other in the reverse; they are quite large and are situated directly above the insertion of the antennae. The thorax as a whole is long, being about two-thirds the length of the abdomen. The prothorax appears to be short and very broad, the anterior margin straight, the sides rounded, and the posterior margin slightly extended at the middle. There is no sign of the prothoracic lobes which are present in the adults of the Protoperlaria. The mesothoracic and metathoracic segments are about equal in size and similar in shape. The fore and hind wing pads are well preserved in the specimen and appear to form a definite part of the mesonotum and metanotum, as in the case of the nymphs of most Perlaria (*e. g.*, Acroneuria). There is a possibility, however, that the wing pads are more detached from the thorax, as in the Perlarian genera Nemoura and Leuctra, since the

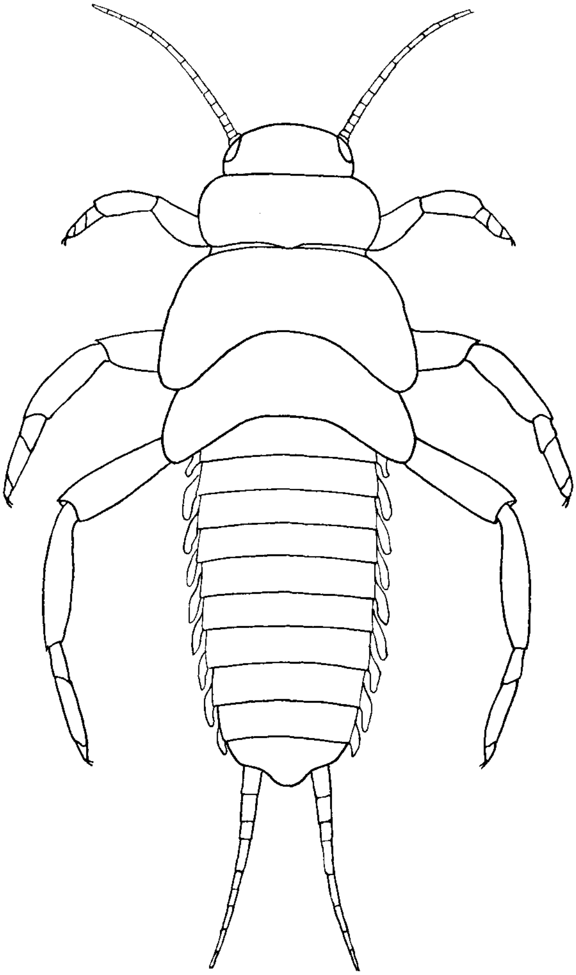

FIGURE 10. Nymph of Protoperlaria, specimen No. 3622*ab*, Museum of Comparative Zoology.

basal portion of the wing pads is not very distinct in the fossil. In their general form the wing pads in the latter are shaped very much like those in Acroneuria, the apex of the wings not extending very far beyond the posterior margin of the mesothoracic and metathoracic segments. The legs, which are finely preserved in the fossil, are unusual in several respects. The fore legs are short, the middle legs somewhat longer, and the hind legs longest. Since all legs are preserved in lateral aspect, the tarsal segmentation does not stand out as clearly as in those specimens showing the legs in dorsal view, but a careful examination of them shows that there are three segments to all the tarsi. The fore leg is 2.7 mm. long, the femur and tibia each 1 mm. long, and the tarsus .7 mm.; the tarsal segments are about equal in length. The middle leg is 5 mm. long, the femur 1.5 mm., tibia 2 mm., and tarsus 1.5 mm.; the 3rd tarsal segment is the shortest, the middle one the longest. The hind leg is 6.5 mm. long, the femur 2.5 mm., tibia and tarsus each 2 mm.; the third tarsal segment is very short, the middle one very long, and the first about one-half the length of the second. Tarsal claws are present on all legs. The abdomen is 5 mm. long and 2.5 mm. wide. Ten segments are distinctly visible from above, all but the last possessing a pair of lateral gills which extend posteriorly as far as the middle of the following segment. The tenth segment is prolonged backwards to form a rounded lobe, as in most recent perlarian nymphs. The cerci are 4 mm. long, stout proximally but slender distally, and contain 8 segments. Fine hairs are present on the proximal segments of the cerci, but no hairs are visible on any other part of this nymph, even on the legs, which in most Recent Perlarians bear a series of long hairs on the tibiae and tarsi as an aid to swimming.

Specimen No. 3619ab, also found in the upper layer of limestone, is 14 mm. long including the cerci, and appears to be identical with the foregoing specimen in all respects; it shows the antennae, middle and hind legs, and cerci very well. The wing pads are especially clear, those on the right side showing definite traces of a few veins. Specimens No. 3620, 3621ab, 3623ab, 3631ab, 3632ab, 3633ab, 3634ab, 3635ab, and 3636ab, all from the upper layer, are fairly well preserved nymphs apparently identical with the two previous fossils.

The best preserved specimen of the group of small nymphs is No. 3611ab, collected by the writer in the upper layer in 1932. This is a complete specimen, 6 mm. long including cerci, showing in excellent preservation one antenna, all 6 legs, cerci, and abdominal gills. The antennae, which are 2 mm. long, contain about 18 segments, the exact number being uncertain because a small portion of the antenna near the middle has been chipped away. As in the previous nymphs,

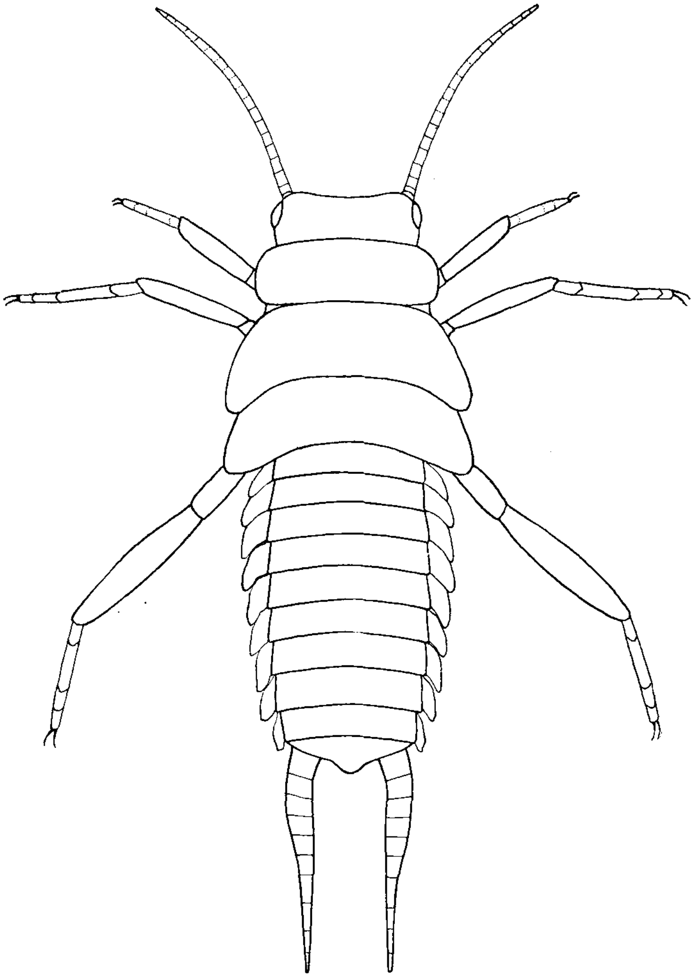

FIGURE 11. Nymph of Protoperlaria, specimen No. 3611*ab*, Museum of Comparative Zoology.

the antenna is stout at the base but slender distally. The head is apparently concave in front and as preserved is three and one-half times as wide as long, although the true length of the head is not visible. The eyes, both of which are well preserved, are about as large as those in the previous nymphs and are similarly situated. The thorax is a little more than one-half as long as the abdomen; the prothorax short, with a slightly rounded anterior border. The wing pads are not quite as prominent as in the previous nymph, but are similar in form. The legs are fairly slender, the fore leg short and the hind leg the longest. The middle and hind tarsi are undoubtedly 4-segmented, but because of the presence of quartz crystals the segmentation of the fore tarsus cannot be determined. The fore leg is 1.3 mm. long, the tibia .8 mm. and the tarsus .5 mm. The first segment of the tarsus is the only one that can be discerned; it is a little longer than wide. The middle leg is 2.3 mm. long, the femur very short, the tibia 1 mm. long, and the tarsus 1.3 mm. long; the first tarsal segment is short, the second twice as long as the first, the third as long as the first, and the fourth about one-half as long as the third. The hind leg is 3.6 mm. long, the femur 1 mm., the tibia, 1.6 mm.. and the tarsus 1 mm.; the tarsal segmentation is similar to that of the middle leg. The tarsal claws are proportionally much larger than those of the foregoing nymphs. The abdomen is 2.5 mm. long, 1.3 mm. wide; each of the first nine segments bears a pair of lateral gills (figure 6, plate 2), proportionally much larger than those of the previous nymphs; the tenth segment is prolonged backwards to form a small lobe. The cerci are 1.8 mm. long, very slight distally but stout basally, with 10 segments, those at the base being as long as wide, the others from two to three times as long as wide.

A second well preserved specimen that appears to be identical with the above small nymph is No. 3630ab. It is 5.5 mm. long, including the cerci, and shows both antennae, one fore leg, both middle and hind legs, and cerci. The following nymphs also seem to be the same species: No. 3612ab, a complete specimen showing some of the abdominal gills very well; No. 3615ab, which has the legs and the abdomen preserved very clearly; No. 3610 and 3617ab, showing the general habitus and legs; and No. 3618ab, in which the legs are very clear. All of these were taken in the upper layer.

There is one nymph (specimen No. 3613) of about the same as the size as those in the preceding lot (6.5 mm. including cerci) which undoubtedly belongs to a very different species. Although the antennae are the same length as those of the foregoing nymphs and contain the same number of segments, the head is much larger and the cerci consist of 8 segments only, the same number as in the large nymphs described above. The femur of the middle and hind legs is fully as long as the tibia, which is certainly not the case with the other small nymphs. The wing pads, which are very well preserved and show both hairs and veins, are much like those of specimen 3611, discussed above. The middle and hind tibiae, at least (the tarsi not being preserved), possess the series of long hairs along the posterior edge present in most Recent Perlarian nymphs; this is a characteristic which I have not seen in any of the nymphs treated in the previous pages. It seems probable, then, that there are at least three species of nymphs represented among the eighty-two specimens, but that there are only such minor differences between the species that we are unable to associate them generically or specifically with the adults.

A comparison of the structure of these nymphs with that of the adults of the Protoperlaria reveals some interesting similarities, one of which is the presence of the lateral abdominal gills on the first nine segments of the nymphs and vestigal abdominal gills on the first nine segments of the adults. As I shall point out more fully later this condition is analogous with the situation in the Recent Perlarian family Eustheniidae, the nymphs of which have functional lateral gills on the first 5 or 6 abdominal segments and the adults vestigial gills on the corresponding segments. The nymphs of some other Perlarians, also, possess indications of such gills, though they are not carried over into the adults. The cerci of the nymphs are very much like those of the adult forms, in both general structure and segmentation. The antennae are considerably shorter than in the adults and the number of segments is much smaller, as is usually the case with nymphs. The most striking difference between the nymphs and adults is the segmentation of the tarsi, there being 5 segments in the adults, but only 3 or 4 in the nymphs. In the nymphs of the Recent Perlarians there are as many tarsal segments in the nymphs as in the adults (three), but in other orders of insects (such as the Plectoptera) it is not unusual for the number of segments to be very different in the immature forms and the adults.

When we compare these Permian nymphs with those of the Recent Perlarians, we also find some interesting similarities and differences. The resemblance between the general habitus is most striking and this is likewise true of the more detailed structure of the thorax and abdomen. The antennae and cerci of the fossils, however, contain a much smaller number of segments than do those of the Recent nymphs. In the latter the antennae have from 35 segments (Chloroperla) to more than 90 (Acroneuria), and the cerci from about 15 segments

(Eustheniidae) to 50 or more (nearly all other genera). In the fossil nymphs the antennae consist of from 13 to 18 segments and the cerci from 8 to 10 segments. In this connection, however, it should be borne in mind that the adult Protoperlaria have much fewer segments in the antennae and cerci than the adult Perlaria. Aside from the difference in the number of tarsal segments, the legs of the Protoperlarian nymphs are not unlike those of the Perlaria, in which there is much diversity of structure. The lateral abdominal gills are perhaps the most interesting and important features of the fossil nymphs. As I have previously mentioned such gills are definitely absent in all Recent Perlarian nymphs, except the members of the family Eustheniidae, where they are present on the first 5 or 6 abdominal segments (Tillyard, 1921). The occurrence of these gills in the Eustheniid nymphs is an important point, since in other respects the members of this family are the most generalized of the true Perlaria. The analogy with the structure in the Protoperlarians is intensified by the fact that the adults of the Eustheniids carry over the abdominal gills in vestigial form. Although these are the only Perlarian nymphs which possess lateral abdominal gills, those of some species of Pteronarcys (e. g. *proteus*) have a pair of lateral processes on each of the first eight segments which in my opinion are modified vestigial gills. So far as I am aware no other explanation has been offered for the presence of these structures.

RELATIONSHIPS OF THE PROTOPERLARIA.

Although in the foregoing pages I have made numerous comparisons between certain structural features of the Perlaria and the Protoperlaria, it seems advisable to summarize in conclusion the differences and similarities between these two orders, and to indicate briefly the evolution of this particular branch of Orthopteroid insects. The similarities between the two groups are so obvious as hardly to require enumeration; they are apparent in the habitus, and the general structure of the antennae, the thorax, wing venation, abdomen and cerci. Even the vestigial gills on the abdomen constitute a point of similarity, since they occur in at least one living family of the Perlaria. It is the differences in the details of the structure of the Protoperlaria and Perlaria which are more interesting and which indicate the phylogenetic relationship of the orders. The most important of these differences are as follows:

1. Tarsal segmentation. In all known Protoperlaria the tarsi are 5-segmented, whereas in all existing Perlaria they are 3-segmented.

2. Prothoracic lobes. Lateral prothoracic lobes or expansions, which are well developed in the Protoperlaria, are entirely lacking in the Perlaria, in which there is at most a broad pronotum. In this connection I again call attention to the presence of prothoracic expansions in many of the other Permian Orthopteroids.

3. Wing venation. Although the wing venation of the Protoperlaria is similar to that of the Perlaria in most respects, the presence of the posterior media (MP) in the former only is a very significant difference. It is to be noted, however, that the proximal part of MP is almost obsolete in the Protoperlaria.

4. Antennal segmentation. The antennae of the Protoperlaria with the exception of those of *Artinska clara*, contain a much smaller number of segments than in the Perlaria, usually about half the number. The condition in *A. clara*, which possesses more antennal segments than any Recent Perlarian, is also unique in having the series of enlarged segments described above.

5. Segmentation of cerci. As in the case of the antennae, the number of segments in the cerci of the Protoperlaria is less than in the Perlaria, although the difference is not so great.

6. Terminal abdominal appendages. In at least two genera of Protoperlaria the female possesses vestigial dorsal and ventral valves (if the interpretation offered above is correct), the dorsal valves being entirely absent in the Recent Perlaria and the ventral valves barely indicated in a few genera.

It is particularly significant that all of these differences, with the possible exception of the 4th, are in characteristics which are more generalized in the Protoperlaria than in the Perlaria. Aside from features which have only generic or specific rank, there are no characteristics of the Protoperlaria which appear to be more specialized than the corresponding ones in the Perlaria. I believe, therefore, that the order Protoperlaria, as defined in this paper, stands in direct evolutionary line leading to the Perlaria, although it is very unlikely that any of the genera now known were the progenitors. The fossils indicate that since the Lower Permian the evolution of this Perlarian line has resulted in the reduction of the number of tarsal segments, the elimination of the prothoracic lobes and the posterior median of the fore wing, the nearly complete loss of the vestiges of an external ovipositor and the lateral abdominal gills of the nymphs and adults. In respect to these and other features the Protoperlaria are intermediate between the true Protorthoptera, for 5-segmented tarsi,[10] prothoracic expansions, an external ovipositor, and a well developed posterior media in the fore wing, were possessed by at least some of the Protorthoptera. The close relationship between the Orthoptera (*s. lat.*) and the Perlaria is now generally recognized by entomologists, and the Perlaria are frequently regarded as Orthoptera which adopted an aquatic mode of existence in the immature stages, forming a divergent branch of the Orthoptera. The Protoperlaria of the Lower Permian appear to represent the beginnings of that divergence.

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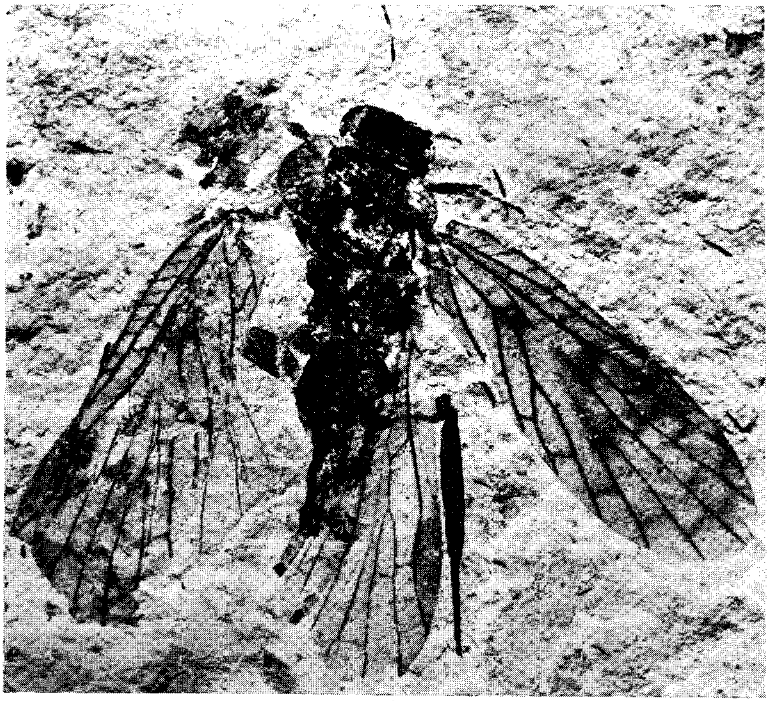
[10] In Shroeder's *Handbuch der Entomologie,* Handlirsch has given reconstructions of nine species of Protorthoptera, in seven of which he has depicted 3-segmented tarsi and in two 4-segmented tarsi. So far as I am aware, there is only one described species of Protorthoptera in which the tarsal segmentation is known,—*Protodianphipnoa* (*Cnemidolestes*) *woodwardi* Brong., from the Carboniferous of Commentry. This was described by Brongniart (Faune ent. terr. prim., 1893, p. 549; pl. 49, fig. 4) as having five tarsal segments, although in Handlirsch's reconstruction it is shown with only four segments (fig. 97).

EXPLANATION OF PLATE I.

FIGURE 1. *Lemmatophora typa* Sellards. Photograph of specimen No. 3536*a*, Museum of Comparative Zoology; length of fore wing, 6 mm.

FIGURE 2. *Lecorium elongatum* Sellards. Portion of abdomen, showing terminal appendages; length of abdomen shown (not including cerci), 2.5 mm.; *c*, cerci; *d*, dorsal valve; *v*, ventral valve.



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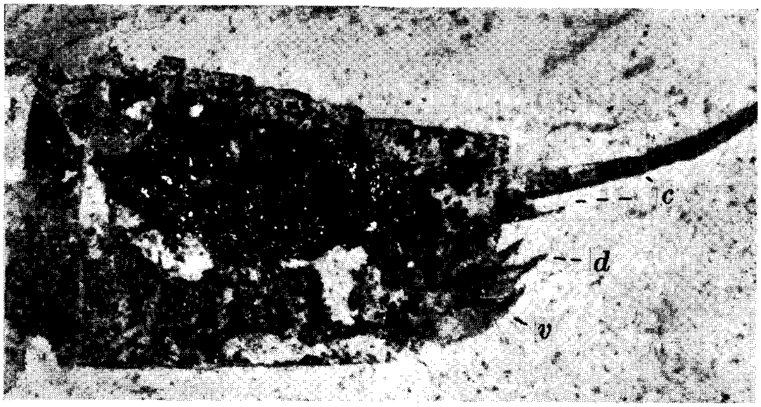

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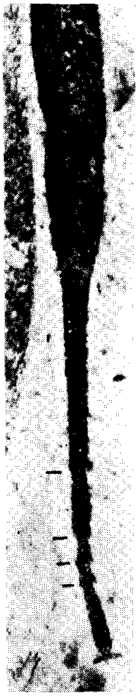
EXPLANATION OF PLATE II.

FIGURE 3. *Lemmatophora typa* Sellards. Photograph of hind femur and tarsus, specimen No. 3536*a*. Museum of Comparative Zoology; dorsal view, showing the five tarsal segments. The short lines indicate the joints between segments. Length of tarsus, 1.5 mm.

FIGURE 4. *Lemmatophora typa* Sellards. Photograph of the femur and tarsus of specimen No. 3536, Museum of Comparative Zoology; lateral view, showing tibial spurs and the five tarsal segments. Length of tarsus, 1.5 mm.

FIGURE 5. *Artinska clara* Sellards. Photograph of antennae of specimen No. 3600, Museum of Comparative Zoology, showing the enlarged segments at regular intervals of 6 segments. The lines indicate the position of the enlarged segments; the other segments are not clearly shown in this photograph except near the end of the antennae. Length of antennae, 9 mm.

FIGURE 6. *Protoperlarian nymph*, photograph of abdomen (specimen No. 3611*a*, Museum of Comparative Zoology), showing lateral abdominal gills (*g*). The left hind wing pad is visible in the upper left corner of the photograph (*p*). Length of part of insect shown in photograph, 1.5 mm.



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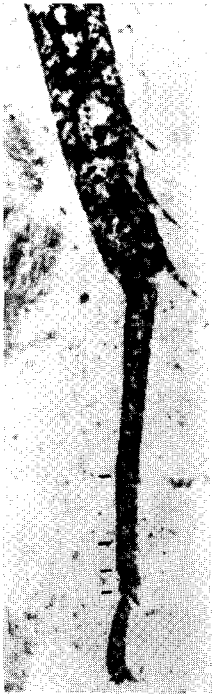

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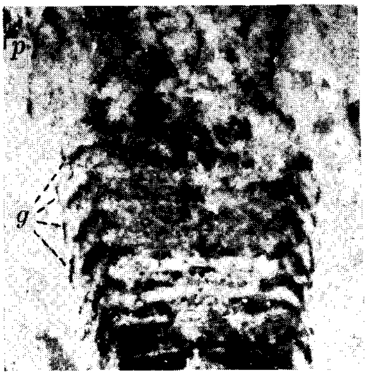

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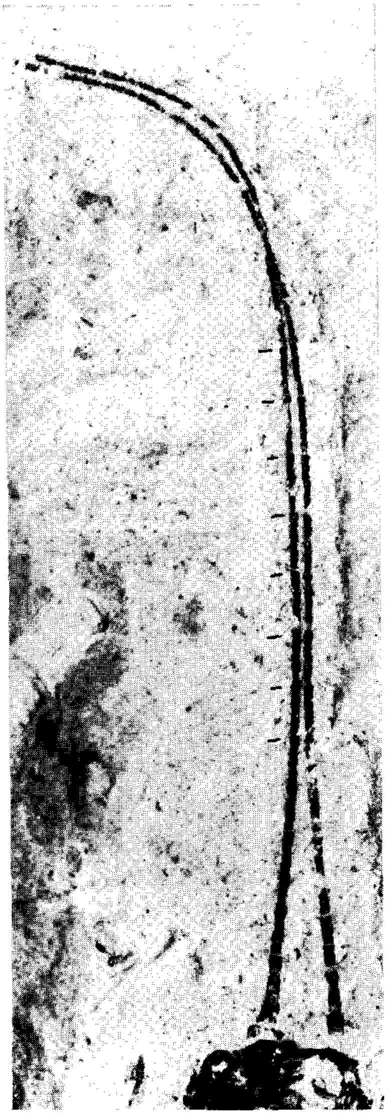

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By Lyman B. Smith

With Four Plates

(Continued from page 3 of cover.)

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VOL. 70, NO. 5—AUGUST, 1935

STUDIES IN THE BROMELIACEAE—VI

1. Preliminary records
2. Synopsis of the Tribe *Tillandsieae*. Part 2

BY LYMAN B. SMITH

WITH FOUR PLATES

STUDIES IN THE BROMELIACEAE—VI[1]

By Lyman B. Smith

Received May 9, 1935 Presented March 13, 1935

1. Preliminary Records

Studies during the past year have resulted in the discovery of several novelties and cases of previously unnoted synonymy, which are put on record here preliminary to a revision of the genera involved.

In preparing the present paper, I have had the good fortune to receive coöperation from a large number of individuals and institutions as is shown by the following list of exsiccatae citations: the Gray Herbarium of Harvard University (G), the Unites States National Museum (US), the New York Botanical Garden (NY), the Brooklyn Botanic Garden (Brooklyn), the Field Museum of Natural History (FM), the Missouri Botanical Garden (Mo), the private herbarium of Prof. L. H. Bailey of Ithaca, New York (Bailey), the University of Michigan (Mich), the University of California (UCal), the Dudley Herbarium of Stanford University (DH), Pomona College (Pom), the Royal Botanic Gardens at Kew (K), the British Museum of Natural History (BM), the University of Cambridge (Cam), the Riks Museum at Stockholm (S), the Botanical Museum of Copenhagen (Ko), the Herbarium of the Botanical Museum at Berlin-Dahlem (B), the Botanical Museum of Munich (Mun), the Rijks Herbarium of Leiden (Ldn), the Muséum National d'Histoire Naturelle at Paris (P), the National Museum of Prague (Prague), the Conservatory of Botany at Geneva (Gen), the Barbey-Boissier Herbarium (Bo), the Herbarium of the Royal Botanic Gardens of Trinidad and Tobago (Trin), the Herbarium of the Botanic Garden of Rio de Janeiro (JB Rio), the National Museum at Rio de Janeiro (MN Rio), the Biological Institute of São Paulo (SP), the private herbarium of Don Cornelio Osten of Montevideo, Uruguay (Ost), the National Museum of Natural History of Buenos Aires (BA), the National Museum at Santiago, Chile (Chile).

I am particularly indebted to Mr. N. Y. Sandwith, Mr. J. E. Dandy, Prof. H. Harms, Don Cornelio Osten and Dr. Alberto Castellanos for critical notes on certain species.

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[1] Contributions from the Gray Herbarium of Harvard University, no. CVI. This paper is divided into (1) Preliminary records (pp. 147 ff.), and (2) Synopsis of the tribe *Tillandsieae*, Part 2 (pp. 156 ff.).

Billbergia decora Poepp. & Endl. Nov. Gen. ii. 42, t. 157 (1838). *B. boliviensis* Bak. Brom. 81 (1889).

PERU: LORETO: province of Maynas near Yurimaguas, *Poeppig 2432* (Gen, TYPE COLLECTION; phot. G); Yurimaguas, lower Rio Huallaga, alt. 135 m., 1929, *Killip & Smith 27646* (G, US, FM); JUNIN: Pichis Trail, Yapas, alt. 1350–1600 m., 1929, *Killip & Smith 25609* (US). BOLIVIA: LA PAZ: Unduavi, alt. 2600 m., 1885, *Rusby 2853* (NY, type of *B. boliviensis;* phot. G).

The type of *Billbergia boliviensis* closely resembles *B. decora* in the shape and size of its sepals as well as in other characters, and nothing remains as a basis for separating the two.

Canistrum perplexum, spec. nov., floriferum ad 4 dm. altum: foliis rosulatis, patentibus, ad 5 dm. longis; vaginis late ellipticis, ad 15 cm. longis, dense minuteque castaneo-lepidotis; laminis lingulatis, 4–5 cm. latis, late rotundatis apiculatisque, minute serrulatis, dissite perobscureque lepidotis: scapo erecto, 4 mm. diametro, dense umbrino-lanato; scapi bracteis late ellipticis, apiculatis, roseis, adpresse lepidotis, unica prope basin scapi, reliquis cyathidium sub inflorescentiam formantibus; inflorescentia percompacte bipinnatim paniculata, 5 cm. longa, 6–7 cm. diametro, dense umbrino-lanata; bracteis primariis late ovatis, mucronatis, integris, quam spicae brevioribus, membranaceis, nervatis: spicis densissimis, paucifloris; bracteis florigeris primariis similibus sed angustioribus, quam sepala paulo brevioribus: floribus sessilibus, 3 cm. longis; sepalis liberis, ellipticis, mucronatis, 19 mm. longis, paulo asymmetricis; petalis lingulatis, obtusis, apiculatis, 20 mm. longis, caeruleis, a ligulis binis elongatis filamenta involventibus auctis; staminibus petala subaequantibus; ovario ellipsoideo, tubo epigyno 2 mm. longo; placentis loculorum ad apicem versus lineatim affixis; ovulis obtusis. Pl. I, figs. 12–15.

BRAZIL: SÃO PAULO: Jardim Botanico, São Paulo, 1934, *Hoehne 31550* (G, TYPE; SP); Alto da Serra, alt. 800–900 m., 1929, *L. B. Smith 1969* (G).

In its coloration and indument this species closely resembles *Canistrum roseum,* but it is smaller and more slender in habit and the appendages on the petals are connate for their entire length. This type of appendage is discussed further on under *Hohenbergia.*

Guzmania Hitchcockiana, spec. nov., florifera metralis (Hitchcock!): foliis ligulatis, 1 m. vel ultra longis, 6 cm. latis, acuminatis, supra glabris, subtus dense minuteque brunneo-lepidotis: scapo ignoto: inflorescentia ample laxeque bipinnata, dense brunneo-lepidota; bracteis primariis inferioribus anguste triangularibus, quam rami axillares subduplo brevioribus: spicis ad 13 cm. longis, longe stipitatis; bracteis florigeris late ovatis, obtusis, 12 mm. longis, sublaevibus, nullo modo carinatis: floribus subpatentibus, crasse pedi-

cellatis, solum fructiferis cognitis; sepalis oblongis, late obtusis, dense lepidotis, ca. 20 mm. longis, ad 10 mm. connatis; petalis staminibusque ignotis. Pl. I, fig. 1.

ECUADOR: GUAYAS: Teresita, 3 km. west of Bucay, alt. 270 m., 1923, *Hitchcock 20436* (US, TYPE; phot. G, NY).

This species is most nearly related to *G. Scherzeriana* Mez from which it differs in its dense brown indument.

Hechtia Meziana, spec. nov., florifera ut videtur fere metralis: foliis ad 8 dm. longis, angustissime triangularibus, 3 cm. latis, utrinque dense adpresseque ferrugineo-lepidotis, spinis ad 6 mm. longis armatis, apice longe attenuatis et inermibus: scapo elongato, gracili, ca. 7 mm. diametro, glabro; scapi bracteis parvis, maxime remotis, ex ovato acuminatis, chartaceis, roseis: inflorescentia perlaxe bipinnatim paniculata, 4 dm. longa et 15 cm. diametro, rosea, glaberrima; bracteis primariis eis scapi similibus, quam bases steriles ramorum subduplo brevioribus; ramis gracilibus, laxe florigeris: bracteis florigeris ovatis, acutis, pedicellos aequantibus vel superantibus, membranaceis: floribus pedicellis usque ad 3 mm. longe stipitatis, femineis solum cognitis; sepalis late triangulari-ovatis, acutis, 4 mm. longis, chartaceis; petalis ovato-lanceolatis, acutis, 9–10 mm. longis, pulchre roseis; filamentis 4–6 mm. longis, antheris abortivis; ovario glabro, stylo brevissimo. Pl. I, figs. 2–3.

MEXICO: CHIAPAS: Rocky banks, ravines near Monserrate, 1925, *Purpus 10276* (NY, TYPE; phot. G).

Hechtia Desmetiana is probably the nearest relative of this species, but differs in having large foliaceous scape-bracts and leaves glabrous above.

Hohenbergia Schult. f. As first conceived, *Hohenbergia* was composed of very diverse elements and it was not until Mez's treatment in the Flora Brasiliensis[1] that it was made homogeneous by taking *H. stellata* as typical and excluding the remainder of the species originally proposed. Later treatments bring the number of species to about thirty, but all follow Mez's definition closely and the limits of *Hohenbergia* may be considered as reasonably well settled.

On the other hand, the position of *Hohenbergia* relative to the other members of the *Bromelioideae* is debatable. Mez and Harms have placed it among the genera characterized by naked petals, although both admit the presence of so-called calli on the petals of *H. stellata* and certain other species. Apparently their stand is that these structures are essentially simple, amounting to little more than slight

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[1] Mez in Mart. Fl. Bras. iii. pt. 3, 263 (1891).

thickenings of the petal and not comparable with such structures as the nectar-scales in *Aechmea*.

On the contrary these structures of *Hohenbergia* are among the most complex in the family, and are equaled in development only in *Gravisia*, *Ananas*, and possibly some species of *Billbergia*. The illustration of the petal of *H. inermis* (Pl. I, fig. 4) shows that these "calli" are in reality slenderly infundibuliform nectar-scales with the side next the petal much produced upward and finally free so that the scale often appears double. I have observed this same structure in *H. caymanensis*, *H. penduliflora*, and *H. Urbaniana*. In *H. spinulosa*, I have found the scales without the upward prolongation, and in *H. eriostachya* and *H. portoricensis* the long ridges but no pockets. This latter type is apparently the one found in *H. stellata* to judge by illustrations. It seems likely that the basic form of the appendage is that illustrated by *H. inermis* and that the other two have evolved from it by reduction.

Hohenbergia should be placed among the genera of the *Bromelioideae* with appendaged petals. It is most nearly related to *Gravisia* which has the identical petal-structure. E. Morren has illustrated this well for *Gravisia exsudans* in Belgique Horticole, xxix. t. 18, although under the name *Hohenbergia exsudans*. In fact no distinction remains between the two genera except the form of the pollen.

Hohenbergia caymanensis Britton in herb., spec. nov., foliis magnis, ca. 8 cm. latis, apice acumine lato brevique imposito optime rotundatis, margine spinis parvis vix 1 mm. longis praeditis, utrinque e lepidibus brunneis minutissime puncticulatis: scapo ca. 8 mm. diametro, e lepidibus ferrugineis dense furfuraceo, vaginis lineari-lanceolatis lepidotis membranaceis minute serrulatis fere omnino obtecto: inflorescentia sublaxe bipinnata, 4 dm. longa, ubique ferrugineo-lepidota; bracteis primariis eis scapi similibus, infimis spicas axillares bene superantibus: spicis densis, ellipsoideis, 3 cm. longis, supremis breviter, infimis ad 2 cm. stipitatis; bracteis florigeris ad 12 mm. longis, e basi triangulari-ovata in setam subaequilongam productis, valde nervatis, supremis sterilibus: floribus ad 14 mm. longis; sepalis liberis, 6 mm. longis, valde asymmetricis, apice in spinam maximam subaequilongam pallidam productis; petalis ex sicco caeruleis, 10 mm. longis, oblongo-lanceolatis, valde acutis, ligulis binis, nectaria profunda angustissime obconica formantibus, apice in vaginam elongatam grosse serratam et cum petalo maxime connatam excurrentibus; staminibus inclusis, seriebus II cum petalis alte connatis; ovulis obtusis. Pl. I, figs. 5–6.

GRAND CAYMAN: 1890–91, *J. T. Rothrock 495* (NY, TYPE; phot. G).

This species is most nearly related to *H. spinulosa* Mez but differs in having the spikes stipitate.

Hohenbergia negrilensis Britton in herb., spec. nov., e fragmentis solum cognita, florifera ut videtur ultra metralis: foliis maximis, crasse coriaceis; laminis ligulatis, 15 cm. latis, apice rotundatis et triangulari-apiculatis, spinis vix 1 mm. longis armatis, supra glabra, subtus dense adpresseque pallido-lepidotis: scapo ca. 7 mm. diametro; scapi bracteis lineari-lanceolatis, acuminatis, densissime imbricatis, chartaceis, pallidis: inflorescentia elongato-thyrsoidea, densissime bipinnatim paniculata, ultra 5 dm. longa, 1 dm. diametro; bracteis primariis eis scapi similibus, perelongatis, infimis spicas axillares triplo superantibus, supremis quam spicae subduplo brevioribus; spicis omnibus sessilibus, suberectis vel patentibus, cylindricis, ad 6 cm. longis, 2 cm. diametro: bracteis florigeris spinula excepta 2–3 mm. longis, 5 mm. latis, latissime acutis vel rotundatis, apice spinula ad 4 mm. longa armatis, plus minusve nervatis; floribus fructiferis 9 mm. longis; petalis staminibusque ignotis; sepalis perasymmetricis, ca. 5 mm. longis, brevi-mucronulatis, pallido-lepidotis; ovario triangulato, appresse pallido-lepidotis. Pl. 1, figs. 7–8.

JAMAICA: Vicinity of Negril, 1908, *Britton & Hollick 2023* (NY, TYPE; phot. G).

Owing to the age of the material any indument there may have been on the axes has disappeared. In habit this species resembles *H. spinulosa* Mez but the floral bracts are much shorter and the mucros of the sepals are very short.

Hohenbergia stellata Schult. f. in R. & S. Syst. vii. 1251 (1830). *H. oligosphaera* (Bak.) Mez in DC. Mon. Phan. ix. 124 (1896). *Aechmea oligosphaera* Bak. Brom. 48 (1889). Pl. I, fig. 9.

Hohenbergia oligosphaera has been separated from *H. stellata* on the basis of having unequal sepals and calli on the petals. An examination of the type of *H. stellata* in the Munich Herbarium shows that the anterior sepal is distinctly shorter than the two posterior ones, and it has already been noted that living material of the species shows appendages on the petals. Thus no distinction remains between the two species and the later *H. oligosphaera* must lapse.

Mezobromelia, gen. nov., foliis integris: floribus quaquaverse ordinatis, hermaphroditis; sepalis symmetricis; petalis intime conglutinatis, intus biligulatis; filamentis cum petalis connatis; ovario supero.

Mezobromelia bicolor, spec. nov., verisimiliter acaulis, florifera fere 5 dm. alta: foliis ad 45 cm. longis, utrinque minutissime perobscureque lepidotis; vaginis ovatis, extus castaneis; laminis ligulatis, acutis, 25 mm. latis: scapo erecto, gracili; scapi bracteis erectis, densissime imbricatis, foliaceis sed supremis fulgide rubris: inflorescentia laxe bipinnatim paniculata, 12 cm. longa; axe glabro, sulcato; bracteis primariis latissime ovatis, fulgide rubris, perobscure lepidotis, infimis longe acuminatis, spicas superantibus, supremis apiculatis, quam spicae bene brevioribus: spicis breviter stipitatis, ellipsoideis, compacte 3–5-floris; rhachi brevi sed distincta; bracteis florigeris oblongolanceolatis, late acutis, ad 16 mm. longis, quam sepala brevioribus, ad apicem carinatis, glabris, chartaceis, valde nervatis: floribus subsessilibus; sepalis aequaliter subliberis, oblongo-lanceolatis, late acutis, 18 mm. longis, carinatis, glabris, nervatis; petalis lingulatis, obtusis, 20 mm. longis, citrinis (Killip!), a ligulis binis triangularibus alte insertis auctis; staminibus inclusis, stylum subaequantibus, filamentis cum petalis alte connatis vel conglutinatis. Pl. I, figs. 10–11.

COLOMBIA: EL VALLE: epiphytic, bushy summit of west peak, La Cumbre, alt. 2100–2400 m., 1922, *Killip 11396* (G, TYPE).

In this genus the structure of the corolla is exactly like that in *Guzmania* except that there are scales alternating with the filaments at their point of attachment to the corolla.

Through the kindness of Mr. A. L. Delisle in preparing microtome sections of *Mezobromelia* and of *Guzmania monostachia*, I have been able to compare the relation of petals in the two in great detail. In neither is the corolla truly gamopetalous, but the petals are so folded and interlocked as to make it seem so even in fresh material (cf. Bot. Mag. t. 5220, fig. 2). In cross-section the edge of one petal appears forked or split and enfolds the filament and the edge of the adjacent petal.

It is a great pleasure to dedicate this genus to Dr. Carl Mez, who has done more than any other botanist to clarify the taxonomy of the *Bromeliaceae*.

Neoregelia bahiana (Ule), comb. nov. *Nidularium bahianum* Ule, Engl. Bot. Jahrb. xlii. 195 (1908). *Aregelia bahiana* Mez, Engl. Pflanzenr. [Heft 100] iv. fam. 32, 42 (1934).

BRAZIL: SÃO PAULO: Alto da Serra, 1933, *Hoehne 31170* (SP, phot. G).

The species is already known from Minas Geraes as well as from Bahia.

Neoregelia carcharodon (Bak.), comb. nov. *Karatas carcharodon* Bak. Brom. 12 (1889). *Nidularium carcharodon* E. Morr. ex Bak. l. c. *Karatas macracantha* Bak. l. c. 8, nomen. *Aregelia carcharodon* Mez in DC. Mon. Phan. ix. 78 (1896).

Neoregelia tristis (Beer), comb. nov. *Bromelia tristis* Beer, Brom. 30 (1857). *Nidularium triste* Regel, Gartenfl. xv. 356 (1866). *Karatas tristis* Bak. Brom. 5 (1889). *Regelia tristis* Lindm. in Öfvers. Akad. Holm. 542 (1890). *Aregelia tristis* Mez in DC. Mon. Phan. ix. 68 (1896).

Pitcairnia kniphofioides, spec. nov., caulescens, florifera ad 75 cm. alta: foliis dimorphis, alteris e vagina triangulari-ovata setiformibus, badiis, margine validissime spinosis, alteris foliaceis, saturate caeruleo-viridibus (Lehmann!), ad 3 dm. longis, subpetiolatis, basi spinosis, laminis late lanceolatis, acuminatis, 4 cm. latis, glabris: scapo erecto, brunneo-floccoso; scapi bracteis supremis ovato-lanceolatis, acutis, glabris, quam internodia bene brevioribus: inflorescentia simplicissima, dense spicata, 12 cm. longa, glabra: bracteis florigeris ovatis, acutis, 2 cm. vel ultra longis, membranaceis, ante anthesin stricte erectis, dense imbricatis et flores obtegentibus, per anthesin deciduis: floribus per anthesin reflexis, subsessilibus; sepalis lanceolatis, late acutis, 15 mm. longis, nullo modo carinatis; petalis quam sepala paulo longioribus, caeruleo-albis, nudis; ovario ad 2/3 supero. Pl. I, fig. 18.

COLOMBIA: CAUCA: terrestrial in damp woods, above Arrayanal on the Rio Ritaralda, alt. 2000 m., 1883, *Lehmann 3310* (Bo, TYPE; phot. G).

Except for the inflorescence from which this species derives its name, it strongly resembles *Pitcairnia nigra*. Its petals, however, are naked.

Puya lasiopoda, spec. nov., e fragmento inflorescentiae solum cognita, florifera verisimiliter magna: inflorescentia laxe bipinnata, tomentoso-lepidota; bracteis primariis ovatis, minutissime serrulatis, submembranaceis, ex sicco rubris, quam rami axillares bene brevioribus sed partem sterilem ramorum excedentibus: racemis spiciformibus densis, ellipsoideis, ad 10 cm. longis et 5 cm. latis, longe graciliterque stipitatis; bracteis florigeris eis primariis similibus sed minoribus integrisque, sepala subaequantibus: floribus erectis, pedicellis graciliter obconicis, ad 7 mm. longis; sepalis anguste lanceolatis, 45 mm. longis, apice uncinatis, nullo modo carinatis; petalis angustissime ellipticis, acutis, 6 cm. longis, ex sicco atro-violaceis; stylo staminibusque elongatis, petala subaequantibus vel post anthesin paulo exsertis; ovulis obtusis. Pl. I, figs. 16–17.

BOLIVIA: EL BENI: Reis, alt. 1500 m., 1886, *Rusby 2232* (NY, TYPE; phot. G).

In the character of its indument and texture of its bracts and sepals this species closely resembles *Puya stenothyrsa* (Bak.) Mez, but its sepals are nearly twice as large, the floral bracts are relatively

much narrower, and the spikes are much denser. The axes are much more tomentose than the bracts, making a noticeably sharp contrast.

In the size and form of its spikes, floral bracts and sepals it resembles *P. oxyantha*, but unlike that species it has spikes that have long slender stipes.

Puya Rusbyi (Bak.) Mez in DC. Mon. Phan. ix. 482 (1896); Mez in Engl. Pflanzenr. [Heft 100] iv. fam. 32, 297 (1935). *Pitcairnia Rusbyi* Bak. Brom. 122 (1889). *Puya Kuntzeana* Mez in DC. Mon. Phan. ix. 490 (1896); Mez in Engl. Pflanzenr. [Heft 100] iv. fam. 32, 308 (1935).

BOLIVIA: LA PAZ: near La Paz, alt. 3300 m., 1885, *Rusby 2846* (NY, TYPE; phot. G); COCHABAMBA: Tunari, alt. 1300 m., 1892, *Kuntze* (NY, type of *Puya Kuntzeana;* phot. G).

In identifying *Puya Kuntzeana* with *P. Rusbyi*, its characteristics, so well defined by Mez, obviate a detailed description of the latter species. *P. Rusbyi* has been misunderstood heretofore because its original description was drawn from *Rusby 2850* as well as from the type. *Rusby 2850* is *P. alpestris*, a native of central Chile. It is labelled as from Bolivia, but as Rusby collected in central Chile in the year that this specimen was gathered, it seems probable that a mixture of labels occurred.

Puya sanctae-crucis (Bak.), comb. nov. *Pitcairnia sanctae-crucis* Bak. Brom. 120 (1889). *Puya floccosa* E. Morr. sensu Mez in DC. Mon. Phan. ix. 478 (1896); Mez in Engl. Pflanzenr. [Heft 100] iv. fam. 32, 294 (1935), quoad plantas bolivianas, non E. Morr. (1889). *Pitcairnia robusta* Rusby, Bull. N. Y. Bot. Gard. vi. 488 (1910). Pl. II, fig. 1.

BOLIVIA: LA PAZ: Songo, 1890, *Bang 892* (G, NY, FM, Mo, BM, Bo); Apolo, alt. 1600 m., 1902, *R. S. Williams 2655* (NY, type of *Pitcairnia robusta;* phot. G); SANTA CRUZ: 1847, *Castelnau* (P, TYPE; phot. G).

In *Puya sanctae-crucis* the indument is deciduous at an early stage, not persistent as in *P. floccosa*. The flowers are much more distinctly pedicellate in *P. sanctae-crucis*, and the whole plant is much more like *P. Pearcei* than it is like *P. floccosa*.

Quesnelia Lamarckii Bak. Brom. 85 (1889). An examination of the type of this species in the Smithian Herbarium of the Linnean Society shows that it must be reduced to the synonymy of *Musa coccinea* Andr.

Tillandsia (§ **Allardtia**) **Cardenasii**, spec. nov., caulescens, florifera 20–25 cm. alta: caule ad 1 dm. longo, simplici: foliis erectis vel suberectis, dense polystiche ordinatis, ad 2 dm. longis; vaginis ovatis, 5 mm. longis, glabris, chartaceis; laminis lineari-triangularibus,

filiformi-acuminatis, basi 8 mm. latis, dense villoseque cinereo-lepidotis, involutis: scapo erecto, 1 mm. diametro, glabro, sulcato; scapi bracteis lanceolatis, internodia superantibus, atro-purpureis, adpresse lepidotis, infimis foliaceo-laminatis: inflorescentia foliis paulo superata, simplicissima, dense 4–7-flora, in circuitu lanceolata, complanata, 5 cm. longa, 1 cm. lata; bracteis florigeris eis scapi similibus sed glabris, dense imbricatis, submembranaceis, nullo modo carinatis, ad 27 mm. longis, sepala superantibus: floribus immaturis solum cognitis, brevissime pedicellatis; sepalis liberis, lanceolatis, acuminatis, ad 20 mm. longis, glabris, nervatis; petalis lingulatis, lilacinis (Cardenas!); staminibus stylum subaequantibus, quam petala paulo brevioribus: capsulis cylindricis, breviter rostratis, bracteas florigeras subaequantibus. Pl. III, figs. 5–6.

BOLIVIA: Chuquisaca: rocky places, Cerro Macho, alt. 2730 m., 1933, *Cardenas 491* (G, type).

Tillandsia caribaea, nom. nov. *T. Fendleri* Mez in DC. Mon. Phan. ix. 741 (1896), non Griseb. (1865).

Tillandsia (§ **Platystachys?**) **lepidosepala**, spec. nov., saepe pulvinata, acaulis vel subacaulis: foliis rosulatis, ad 15 cm. longis, dense pruinoseque cinereo-lepidotis; vaginis late ovatis vel suborbicularibus, nullo modo inflatis, 10–15 mm. longis; laminis erectis vel patentibus, lineari-triangularibus, acuminatis, basi 7 mm. latis, involutis: scapo brevi, foliis fere abscondito; scapi bracteis erectis, foliaceis, densissime imbricatis, inflorescentiam subaequantibus: inflorescentia fructifera solum cognita, simplicissima, dense 2–5-flora, foliis superata; bracteis florigeris lanceolatis, acutis, 20–35 mm. longis, sepala aequantibus vel superantibus, quam internodia 3–4-plo longioribus, submembranaceis, nullo modo carinatis, densissime cinereo-lepidotis: floribus sessilibus; sepalis liberis, lanceolatis, acuminatis, ad 20 mm. longis, valde nervatis, dense lepidotis, lateralibus carinatis; petalis genitalibusque ignotis: capsulis cylindricis, breviter rostratis, bracteas florigeras subaequantibus. Pl. II, figs. 2–3.

MEXICO: Hidalgo: near Tula, 1905, *Rose, Painter & Rose 8283* (US); Michoacan: on trees near Lake Cuitzeo, 1892, *Pringle 5323* (G, type); Puebla: Teocalli de Cholula, alt. 2224 m., 1907, *Arsène 1846* (US); Malintze, 1910, *Nicolas 5742* (US).

This species has until now been confused with *T. Ehrenbergiana*, from which it differs in its nearly acaulescent habit and very densely imbricate foliaceous scape-bracts.

Tillandsia Reichenbachii Bak. Brom. 166 (1889). *T. tucumanensis* Mez in DC. Mon. Phan. ix. 853 (1896). *T. Herzogii* Wittm. Mededell. Rijks Herb. xxix. 89 (1916).

BOLIVIA: Santa Cruz: "monte" near Cumbarute, alt. 800 m., 1910, *Herzog 1151* (Ldn, type of *T. Herzogii;* B, phot. G); Charagua, alt. 800 m., 1934, *Cardenas 2682* (G). ARGENTINA: Jujuy: San Pedro de Jujuy, alt. 600 m., 1925, *Schreiter 153* (G, Ost, BA); 1926, *Venturi 5326* (G, FM, Mo); Salta: dept. Guachipas, Alemania, alt. 1300 m., 1929, *Venturi 9883, 10018* (G); Tucuman: sketch of living plant in Hamburg gardens brought from Tucuman (K, type; phot. G); Barranca Colorada near Tucuman, 1873, *Lorentz & Hieronymus* (B, type of *T. tucumanensis;* phot. G); Quebrada de San Rafael, 1918, *Schreiter 27/2349* (G, BA); Campo Alegre, alt. 400 m., 1922, *Schreiter 802* (Ost); dept. Burroyacu, Cerro del Campo, alt. 800 m., 1928, *Venturi 7759* (G, Mo).

Although *Tillandsia Reichenbachii* is based only on a crude sketch, there seems to be sufficient evidence to establish its identity. The sketch shows a plant with a short stem, polystichous leaves, and large suborbicular petal-blades. This immediately reduces the possibilities in Tucuman, the type locality, to two species, *T. Duratii* and one that has been going under the name of *T. tucumanensis*. *T. Duratii* has circinnate leaves that are much stouter than those of *T. tucumanensis*. The sketch of *T. Reichenbachii* definitely shows the fine filiform-acuminate leaves of *T. tucumanensis* which are merely curved and not circinnate. Furthermore, material of so-called *T. tucumanensis* gathered in Tucuman, *Venturi 7759*, shows that plants with compound and simple inflorescences may occur in the same collection. Thus it is evident that *T. Reichenbachii* must include the later *T. tucumanensis*. The identity of *T. Herzogii* with *T. Reichenbachii* has been overlooked heretofore because of the scant knowledge of the latter species, and probably also because the types came from different countries.

2. Synopsis of the Tribe Tillandsieae. Part 2.

The following installment of the synopsis consists of a revision of those species of *Tillandsia* which have a simple distichous- or single-flowered inflorescence and caulescent habit. Such a treatment is necessarily somewhat artificial in character, cutting across several of the natural sections of *Tillandsia* in order to achieve its primary aim of providing a rapid key for fruiting material. Yet about half of these species belong to the sections *Phytarrhiza* and *Diaphoranthema* between which the transition is so gradual that they may be considered as presenting a solid block of species. The unrelated elements come from *Allardtia*, *Anoplophytum* and *Platystachys*.

It should be understood here that I have changed the typification of *Anoplophytum*, making its transversely plicate filaments diagnostic, and have reduced the sections *Pityrophyllum* and *Aerobia* to *Platy-*

stachys and *Allardtia* respectively. *Pityrophyllum* is not tenable because the break between a paniculate inflorescence with few-flowered distichous spikes and one of a single polystichous-flowered spike is no stronger here than it is within the sections *Allardtia* and *Anoplophytum*. *Tillandsia brachycaulos* Schdl., for instance, may have either type of inflorescence according to the vigor of its growth, just as may *T. biflora* R. & P. of the section *Allardtia*. *Aerobia* supposedly had more deeply included stamens than *Allardtia*, but in checking the latter I find that there is every degree of transition from barely included to deeply included stamens.

In addition to the natural groupings included, the plants in this revision derive a unity of their own from certain characters corollary to their caulescent habit. In all the species, for example, the leaf-blades are relatively thick and are either linear or narrowly triangular, never lingulate. In most cases they are plants of distinctly xerophytic habitat and have the scales on the leaves strongly developed.

The distinction between simple and compound inflorescences is an extremely convenient one in handling fruiting material. In the large majority of cases a given species is limited to one category or the other, being what we might term "obligate-simple" or "obligate-compound." In a small proportion of cases, a species while normally of one type may at times be the other, or what may be termed "facultative-simple" or "facultative-compound." In the latter case the species is treated in the part of the synopsis dealing with its normal state, but is keyed in parenthesis in the part dealing with its facultative state.

In citing material certain specimens are cited on the authority of others when it has not been possible for me to examine them personally and where the species are well marked and generally agreed upon. In such cases the authority and an exclamation mark are enclosed in parenthesis immediately following the specimen.

Certain species of this revision are so common that it has been necessary to abridge their bibliography and the citation of their specimens but in all cases the really significant literature is given and enough specimens are cited to illustrate the present knowledge of their distribution.

KEY TO SPECIES

1. Spikes with flowers distichous or secund, or else the inflorescence reduced to a single flower.
    2. Sepals asymmetric, free, oblong or broadest near the apex, not over 10 mm. long. . . . . *Tillandsia* § *Pseudo-Catopsis*.[1]

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[1] CONTRIB. GRAY HERB. lxxxix. 15 (1930).

2. Sepals symmetric, or if slightly asymmetric, ovate or lanceolate, broadest near the base.
3. Inflorescence of a single spike or reduced to a single flower, either terminal or pseudoaxillary.
4. Plant caulescent: leaf-blades linear or triangular. *Tillandsia* in part.
5. Leaves polystichous.
6. Leaves much more than 15 mm. long: plant not at all moss-like.
7. Scape-bracts more than 2 when the scape is present, always concealing the greater part of the scape and usually imbricate.
8. Inflorescence more than 2-flowered, usually scapose.
9. Floral bracts and flowers erect at anthesis, diverging only in so far as they are forced to make room for those directly above them.
10. Leaf-blades less than 3 times as long as the barely distinct sheaths, (Cf. pl. III, fig. 1).
11. Floral bracts prominently nerved, lepidote.
12. Inflorescence scapose: petals blue or violet. Peru................1. *T. cauligera.*
12. Inflorescence sessile: petals rose. Peru. 2. *T. Macbrideana.*
11. Floral bracts nearly or quite even, glabrous. Argentina..................3. *T. Friesii.*
10. Leaf-blades many times longer than the usually distinct sheaths. (Cf. pl. III, figs. 2, 5, 7).
13. Inflorescence dense: floral bracts nearly or quite twice as long as the internodes.

(See continuation)

(Continuation)

14. Floral bracts not more than 20 mm. long.
15. Floral bracts ovate or lanceolate, not (or very minutely) apiculate.
16. Floral bracts evenly convex, not at all carinate.
17. Floral bracts equaling or exceeding the sepals.
18. Sepals glabrous.
19. Floral bracts merely acute: spike linear or lance-linear in outline. (Cf. pl. II, fig. 4).
20. Leaves pungent, appressed- or subpruinose-lepidote.
21. Floral bracts glabrous, faintly nerved. Peru, Bolivia............................4. *T. caulescens.*
21. Floral bracts densely lepidote, strongly nerved. Brazil..................................5. *T. dura.*
20. Leaves with soft filiform-acuminate apices, tomentose-lepidote.
22. Leaves abruptly spreading from the base of the blade, widely spaced. Colombia, Peru, Bolivia, Chile...............................18. *T. paleacea.*
22. Leaves strict and rather dense. Paraguay..19. *T. arhiza.*
19. Floral bracts acuminate: spike broadly lanceolate or oblanceolate. (Cf. pl. II, fig. 5). Argentina..12. *T. argentina.*
18. Sepals densely lepidote. Colombia, Ecuador..13. *T. incarnata.*

17. Floral bracts distinctly shorter than the sepals.

23. Plants long-caulescent: leaves mostly shorter than the stem.

24. Leaves abruptly spreading from the base of the blade, widely spaced. Colombia, Peru, Bolivia Chile. 18. *T. paleacea.*

24. Leaves strict and rather dense. Paraguay......19. *T. arhiza.*

23. Plants short-caulescent: leaves much longer than the stem.

25. Leaves strongly pruinose- or tomentose-lepidote. Brazil, Peru, Bolivia, Paraguay..........(*T. streptocarpa.*)[1]

25. Leaves appressed-lepidote.

26. Leaf-blades slender, filiform-acuminate, barely if at all circinnate: floral bracts glabrous. Bolivia, Argentina...........................(*T. Reichenbachii.*)[1]

26. Leaf-blades stout, pungent, strongly circinnate: floral bracts usually lepidote. Bolivia, Paraguay, Uruguay, Argentina......................(*T. Duratii.*)[1]

16. Floral bracts sharply carinate: flowers often viviparous. Colombia, Ecuador, Peru.........................(*T. latifolia.*)[1]

15. Floral bracts suborbicular, membranaceous, the lower ones long-apiculate. Cuba to northern Argentina..........(*T. pulchella.*)[2]

14. Floral bracts distinctly more than 20 mm. long.

27. Sepals densely and persistently lepidote.

28. Scape-bracts foliaceous: scape very short. Mexico..(*T. lepidosepala.*)

28. Scape-bracts or at least the upper ones thin and not at all foliaceous.

29. Leaf-blades 10–17 mm. wide, flat except near the apex, appressed- or slightly pruinose-lepidote. Colombia, Ecuador...13. *T. incarnata.*

29. Leaf-blades 3 mm. in diameter, involute, villous-lepidote. Mexico................................14. *T. Ehrenbergiana.*

27. Sepals glabrous.

30. Floral bracts obtuse and often apiculate, membranaceous: inflorescence terete at anthesis: leaf-sheaths suborbicular, not at all auricled. Mexico and the West Indies to Venezuela and Colombia............................15. *T. Schiedeana.*

30. Floral bracts acute or acuminate: inflorescence usually complanate.

31. Floral bracts all densely and persistently lepidote: scape largely obscured by the leaves. Bolivia..........(*T. boliviensis.*)

31. Floral bracts glabrous or the lowest with a few early deciduous scales.

32. Scape appearing nearly as thick as the inflorescence because of its very densely imbricate bracts: flowers viviparous. Chile..........................6. *T. Werdermannii.*

32. Scape appearing distinctly more slender than the inflorescence: flowers never viviparous.

33. Leaves reflexed-tomentose with very fine elongate scales: leaf-blades only 8 mm. wide at base. Bolivia. 7. *T. Cardenasii.*

33. Leaves appressed- or coarsely pruinose-lepidote with suborbicular scales.

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[1] Inflorescence normally compound, species to be treated in later article.

[2] Inflorescence typically simple and polystichous-flowered, but a single specimen known, *Wilkes Expedition* (G), from Brazil, with a reduced simple distichous-flowered inflorescence.

34. Stem shorter than the densely massed leaves.

35. Floral bracts not over 40 mm. long: scape always elongate: sepals obtuse.

36. Leaves with soft filiform-acuminate apices: stem very short. Chile................8. *T. Geissei.*

36. Leaves with straight pungent or subpungent apices.

37. Floral bracts rarely more than 25 mm. long: petal-blades narrowly elliptic.

38. Floral bracts prominently nerved: leaves evenly fine-acuminate. Bolivia, Brazil, Paraguay, Argentina...........(*T. Lorentziana.*)

38. Floral bracts even except near apex: leaves gradually narrowed to an abruptly acute apex. Argentina......12. *T. argentina.*

37. Floral bracts 25–40 mm. long: leaves gradually narrowed to an abruptly acute apex: petal-blades large, suborbicular. Uruguay. 9. *T. arequitae.*

35. Floral bracts up to 70 mm. long: scape usually short and concealed by the leaves: petal-blades large, suborbicular. Bolivia, Uruguay, Argentina..............................10. *T. xiphioides.*

34. Stem longer than the few-ranked widely spaced spreading leaves: petal-blades large, suborbicular. Argentina...........................11. *T. diaguitensis.*

13. Inflorescence lax: floral bracts much less than twice as long as the internodes.

39. Plant large, long-caulescent: sepals ca. 20 mm. long. Mexico..........16. *T. albida.*

39. Plant small, short-caulescent: sepals ca. 9 mm. long. Peru, Bolivia, Brazil, Paraguay, Uruguay, Argentina..24. *T. loliacea.*

9. Floral bracts and flowers spreading at anthesis. Ecuador, Peru.....................20. *T. caerulea.*

8. Inflorescence 1–2-flowered, sessile. Venezuela. 17. *T. Funckiana.*

7. Scape-bracts not more than 2: scape exposed for most of its length.

40. Floral bracts glabrous: stem not over 6 cm. long.

41. Floral bracts prominently nerved: scape-bracts one or none. Argentina........25. *T. erecta.*

41. Floral bracts even: scape-bracts 2. Bolivia, Argentina.........................26. *T. funebris.*

40. Floral bracts densely appressed-lepidote: stem up to 20 cm. long. Argentina..........36. *T. andicola.*

6. Leaves not more than 15 mm. long: plant resembling a coarse moss or a *Lycopodium.*

42. Scape bracteate throughout: inflorescence usually of several flowers. Bolivia, Brazil, Paraguay, Argentina...........................27. *T. tricholepis.*

42. Scape naked when present or with 1–2 bracts: inflorescence always 1-flowered.

43. Floral bract 1-nerved: leaf-sheaths 3-nerved. Peru, Bolivia, Argentina..............28. *T. bryoides.*

43. Floral bract several-nerved: leaf-sheaths 4–many-nerved.
44. Leaves erect: inflorescence distinctly scapose in most cases. Argentina .... 29. *T. aizoides.*
44. Leaves spreading to recurved: inflorescence subsessile. Argentina .... 30. *T. angulosa.*
5. Leaves distichous.
45. Floral bracts 4–5 cm. long. Argentina... 11. *T. diaguitensis.*
45. Floral bracts ca. 2 cm. long at most.
46. Stem rarely over 2 dm. long, wholly concealed by the imbricate leaf-sheaths.
47. Leaf-blades narrowly triangular, mucronate, usually well over 2 mm. in diameter.
48. Leaves spreading or recurved.
49. Leaves rarely more than 2 cm. long: scape not over 4 cm. long.
50. Floral bracts and sepals prominently nerved, floral bracts densely lepidote. Argentina .... 30. *T. angulosa.*
50. Floral bracts and sepals nearly or quite even, not more than scantly lepidote. Argentina .... 31. *T. rectangula.*
49. Leaves 2–30 cm. long: scape often elongate.
51. Floral bracts glabrous.
52. Floral bracts and sepals even: leaf-blades strongly angled. Bolivia, Argentina...................... 26. *T. funebris.*
52. Floral bracts and sepals prominently nerved: leaf-blades terete. Argentina. 32. *T. Castellani.*
51. Floral bracts densely lepidote.
53. Leaves tomentose-lepidote. Bolivia, Brazil, Uruguay, Argentina.... 21. *T. crocata.*
53. Leaves appressed- or slightly pruinose-lepidote.
54. Stem not over 10 cm. long, usually shorter than the leaves.
55. Leaf-blades laterally compressed: leaf-sheaths indistinct, but little broader than the blades, enfolding the stem only by their extreme base. Peru, Bolivia, Argentina. 33. *T. Gilliesii.*
55. Leaf-blades terete: leaf-sheaths distinct, much broader than the blades, enfolding the stem for most of their length.
56. Sepals equally subfree: scape usually elongate. Bolivia, Uruguay, Argentina........ 34. *T. myosura.*
56. Sepals much connate posteriorly: scape 55 mm. long at most. Argentina............... 35. *T. retorta.*
54. Stem 20 cm. long, many times longer than the leaves: sepals connate posteriorly. Argentina........ 36. *T. andicola.*

48. Leaves erect: sepals connate posteriorly: scape naked. Peru, Bolivia, Paraguay, Argentina, Chile............................39. *T. capillaris.*

47. Leaf-blades linear, usually obtuse, not over 2 mm. in diameter.

57. Sepals free or equally short-connate.

58. Floral bracts glabrous or scantly lepidote, at most barely longer than the internodes. Bolivia, Paraguay, Uruguay, Argentina. 22. *T. bandensis.*

58. Floral bracts densely lepidote, twice as long as the internodes or the inflorescence 1-flowered.

59. Sepals lepidote: 2 or 3 scape-bracts immediately below the first floral bract: stem up to 2 dm. long. Peru, Chile. 37. *T. Landbeckii.*

59. Sepals glabrous, or if lepidote, then only a single scape-bract immediately below the first floral bract.

60. Sepals 12.5 mm. long: petal-blades suborbicular, 6.5 mm. broad, blue or violet. Brazil............23. *T. Mallemontii.*

60. Sepals not more than 9 mm. long, (much shorter within the range of *T. Mallemontii*): petal-blades narrowly elliptic, pale violet or white. Southern United States to Argentina...38. *T. recurvata.*

57. Sepals connate posteriorly: scape without bracts or absent. Peru, Bolivia, Paraguay, Argentina, Chile..................39. *T. capillaris.*

46. Stem several meters in length, exposed between alternating bunches of leaves. Southern United States to Argentina and Chile............40. *T. usneoides.*

4. Plant acaulescent: leaves often ligulate.[1]

3. Inflorescence compound.[1]

1. Spikes with flowers polystichous.[1]

1. **Tillandsia** (§ **Allardtia**) **cauligera** Mez. Plant 45 cm. long: stem simple so far as known, at least 6 dm. long, 5–7 mm. thick: leaves densely polystichous, 21 cm. long, cinereous, densely pruinose-lepidote; sheath 30–45 mm. broad, ovate but merging indistinguishably into the blade, half as long as the blade; blades suberect or slightly secund, triangular, acuminate, rigid, apex often uncinate-recurved, margin undulate: scape distinct, terminal, erect, 3–25 cm. long, from shorter than to much exceeding the leaves; its bracts numerous, densely imbricate, striate-nerved, densely lepidote, the median and lower ones foliose and more or less laminate, the upper ones acute or apiculate and thinner, often bright red: inflorescence usually simple and distichous, occasionally a small second spike;

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[1] To be treated in later articles.

primary bract when present shorter than the spike and resembling the scape-bracts; spike lanceolate or linear-lanceolate, acute, complanate, 8–9 cm. long, densely 10–14-flowered; rhachis slightly flexuous, strongly 4-angled, glabrous; floral bracts erect, densely imbricate, 3–4 times as long as the internodes, completely concealing the rhachis, ovate, narrowly obtuse, 20–25 mm. long, exceeding the sepals, not at all carinate, uniformly chartaceous, reddish, lepidote on the apex and margins, striate: flowers short-pedicellate; sepals elliptic, broadly acute or obtuse, 18 mm. long, chartaceous, striate, coarsely sparse-lepidote soon becoming glabrous, connate posteriorly for 3 mm.; petals 37 mm. long, blue, drying violet; stamens and style included.—Saxicolous; Peru.—Mez in Fedde Rep. Spec. Nov. iii. 42 (1906); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 119 (1930).—SALVAJINA; OQUENHUEYCONTOY.—Pl. III, fig. 1.

PERU: CAJAMARCA: Hacienda La Tahona, near Hualgayoc, alt. 2600 m., *Weberbauer 4050* (B, TYPE; phot. G); JUNIN: between Tarma and Palca, alt. 2700–3000 m., *Weberbauer 2415* (B); Tarma, alt. 3000–3200 m., 1929, *Killip & Smith 21803* (G, FM, US); CUZCO: Ollantaytambo, alt. 3000 m., 1915, *Cook & Gilbert 568; 785* (US); Cuzco, alt. 3000–3600 m., 1923, *Herrera* (US).

2. **Tillandsia** (§ **Allardtia**) **Macbrideana** L. B. Smith. Plant over 3 dm. long: roots present: stem much branched, also sending out slender stolons with reduced leaves: leaves polystichous, densely imbricate, 3–4 cm. long, densely appressed-lepidote, cinereous; sheath broadly elliptic, 15–20 mm. wide, scarcely distinct from the blade and over half as long; blade triangular, acuminate, recurved near apex: scape lacking: inflorescence terminal, simple and distichous, lanceolate, acute, up to 4 cm. long, 15 mm. broad, 5–10-flowered; rhachis nearly straight, glabrous, sulcate, excavated next the flowers; floral bracts erect, imbricate, 3–4 times as long as the internodes but so narrow as to expose most of the rhachis at anthesis, lanceolate, broadly acute or obtuse, 2 cm. long, exceeding the sepals, not at all carinate, closely striate, submembranaceous, at first densely appressed-lepidote, later glabrous, chartaceous, rose: flowers subsessile; sepals narrowly lanceolate, strongly carinate, glabrous, striate, connate posteriorly for 5 mm.; petals 25 mm. long, narrowly elliptic, obtuse, rose; stamens slightly longer than the style, emerging from the throat of the corolla but shorter than the petals, anthers very narrow, 7 mm. long, filaments straight; ovary 3 mm. long, ovoid: fruit not known, possibly not developed and the species propagating solely by stolons. —Saxicolous; Peru.—L. B. Smith in Contrib. Gray Herb. lxxxix. 11, t. 2, figs. 1–3 (1930).

PERU: Huanuco: on eastern face of rock cliffs, Llata, alt. 2100 m., *Macbride & Featherstone 2258* (FM, type; G, cotype).

The single old and withered inflorescence at hand shows no evidence of capsules, indicating that the species probably reproduces vegetatively but has not gone so far as *T. Werdermannii* in changing the flower.

In publishing this species I noted the fact that the stamens exceeded the style, and stressed it as indicating some affinity with the section *Anoplophytum*. Since then I have found that this character is of no value in distinguishing *Anoplophytum* from *Allardtia,* and that the really valid distinction of *Anoplophytum* is its transversely plicate filaments.[1]

3. **Tillandsia** (§ **Allardtia**) **Friesii** Mez. Plant distinctly caulescent: stem ca. 15 cm. long, decumbent-ascending: leaves densely polystichous, not at all secund, up to 7 cm. long; sheaths oblong-elliptic, glabrous and enfolding the stem only at the extreme base; blades narrowly triangular, acuminate, 7–9 mm. broad, stiff, complicate toward apex, coarsely cinereous-lepidote throughout, subpruinose, sometimes blackish: scape lacking: inflorescence terminal or axillary, simple, dense, not more than 6-flowered, sessile and about equaling the leaves, sublanceolate, complanate, up to 5 cm. long and 1 cm. broad, glabrous throughout; rhachis slightly flexuous, angled; floral bracts erect, imbricate but so narrow as to expose the rhachis, ovate, broadly acute, ca. 17 mm. long, exceeding the sepals, somewhat rigid, even and slightly lustrous, ecarinate, bright red: flowers subsessile, erect, ca. 20 mm. long; sepals lanceolate, acute, 13 mm. long, chartaceous, even or faintly nerved, free; petals purple (Fries!), bright red when dry, obtuse, forming a slightly flaring tube; stamens included, shorter than the pistil.—Saxicolous; northern Argentina.—Mez in Fedde Rep. Spec. Nov. iii. 37 (1906). Pl. II, fig. 11.

ARGENTINA: Salta: Tambo in Quebrada del Toro, alt. 3000 m., *R. E. Fries 828* (S, type; phot. G).

4. **Tillandsia** (§ **Allardtia**) **caulescens** Brongn. Plant up to 45 cm. long: roots present even in age: stem much branched, up to 30 cm. long: leaves very numerous, densely polystichous, rigid, strict or arching and secund, 10–15 cm. long, densely appressed- or subpruinose-lepidote throughout; sheath subtriangular, several times shorter than the blade; blade narrowly triangular, ca. 5 mm. broad at base, acuminate, involute, pungent, usually with a strong median ridge below: scape distinct to almost none, usually much obscured by the leaves,

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[1] L. B. Smith in Ostenia, 360 (1933); Proc. Am. Acad. lxviii. 149 (1930).

terminal, straight or curved; its bracts densely imbricate, the lower ones foliose, the upper ones elliptic, acute or apiculate, nerved, roseate, more or less lepidote: inflorescence always simple and distichous, linear or lance-linear in outline, acute, strongly complanate, up to 14-flowered, 5–7 cm. long, 10–12 mm. wide; rhachis slightly geniculate, strongly 4-angled, glabrous; floral bracts erect, densely imbricate, over 3 times the length of the internodes, but partially exposing the rhachis, ovate-lanceolate, acute, 15–20 mm. long, exceeding the sepals, convex, not at all carinate, subcoriaceous, faintly nerved, glabrous, roseate: flowers subsessile, 25 mm. long; sepals lanceolate, acute, 15 mm. long, glabrous, even or faintly nerved, equally subfree or connate posteriorly up to 3 mm.; petals lingulate, white, spreading at anthesis; stamens emerging from the throat of the corolla, shorter than the style; ovary ovoid-pyramidal.—Peru, Bolivia.—Brongn. ex Bak. Brom. 168 (1889); Mez in DC. Mon. Phan. ix. 811 (1896); F. L. Herrera, Est. Fl. Dep. Cuzco, 76 (1930). Pl. II, fig. 4.

PERU: CUZCO: near Ollantaitambo, province of Urubamba, alt. 2900 m., 1925, *F. L. Herrera 825* (US, G, FM); INDEFINITE: *C. Gay 1186* (P, TYPE; phot. G); Quebrada Versalles, *A. Diehl 2451* (FM). BOLIVIA: LA PAZ: vicinity of Bopi River Valley, alt. 1000 m., 1921, *Rusby 670* (NY); vicinity of Huachi, head of Beni River, alt. 600 m., 1921, *O. E. White 536* (NY); same, alt. 500 m., *O. E. White 1068* (NY, phot. G).

5. **Tillandsia** (§ **Allardtia**) **dura** Bak. Plant 2–4 dm. long: roots present even in age: stem almost always simple, from very short to about 14 cm. long: leaves very numerous, polystichous, strict or somewhat arching and often secund, 15–23 cm. long, densely and finely appressed-lepidote throughout, becoming subglabrous above with age, chestnut-brown for the entire length of the sheath and much of the blade, the remainder pale gray-green in the dried material; sheath ovate, scarcely more than 1 cm. long, passing imperceptibly into the blade; blade narrowly triangular, up to 11 mm. broad at base (Mez!) but usually much narrower, rigid, subulate-acuminate: scape distinct but usually much obscured by the leaves, terminal, slender, erect or ascending; its bracts many, densely imbricate, ovate, thin, densely and finely appressed-lepidote, the median and lower ones with stiff leaf-like blades: inflorescence always simple and distichous, the spike linear, acute, strongly complanate, 14–26-flowered, 7–13 cm. long, 10–14 mm. wide; rhachis slightly geniculate, sulcate, angled, distinctly excavated next the flowers, glabrous; floral bracts erect, strongly imbricate, often 3 times the length of the internodes, but so narrow as partially to expose the rhachis, ovate, acute, apiculate,

17–20 mm. long, exceeding the sepals, subchartaceous, strongly nerved, densely appressed-lepidote toward apex, grooved at base, rounded or carinate toward apex, straight or slightly incurved: flowers subsessile; sepals free or equally short-connate or at times the posterior ones connate for about half their length, 8–11 mm. long, oblong-lanceolate, acute, strongly nerved, glabrous, the posterior ones carinate; petals lingulate, blue, 17 mm. long; stamens included, anthers linear, acute, 5 mm. long, dorsifixed 1/4–3/5 of their length from the base; pistil exceeding the stamens, ovary slenderly ovoid.—Saxicolous and epiphytic; Brazil.—Bak. Brom. 168 (1889); Mez in Mart. Fl. Bras. iii. pt. 3, 584, t. 108 (1894); Mez in DC. Mon. Phan. ix. 811 (1896); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 119 (1930). *T. lineáris* Vell. sensu Wawra, Oesterr. Bot. Zeitschr. xxx. 221 (1880); It. Sax.-Cob. i. 174 (1883), non Vell. (1825).

BRAZIL: FEDERAL DISTRICT: Rio de Janeiro, Pico da Tijuca, *Glaziou 16460* (K, TYPE; phot. G); 1929, *L. B. Smith 2126* (G, S, B); *Wawra II, 223* (Mez!); *Binot* (Mez!); Rio de Janeiro, Serra da Carioca, alt. 460–720 m., 1928, *L. B. Smith 1280* (G, FM, US, K, BM); SÃO PAULO: on trees by shore, São Vicente, Santos, 1875, *Mosén 3716* (S, phot. G); Ribeirão Pires, 1894, *Edwall in hb. S. P. 12390* (G, SP); epiphytic in matto, Estação Biologica, Alto da Serra, alt. 800–900 m., 1929, *L. B. Smith & J. King 1933* (G).

In *Tillandsia* as a rule the character of sepal fusion is a fairly constant and reliable one, but in *T. dura* it fails to hold. The *Edwall* specimen, while closely simulating the rest of the material in all other regards, has the posterior sepals fused for about half their length. All other numbers have the sepals nearly or quite free.

T. dura seems to be more nearly related to *T. caulescens* than to any other species. It resembles *T. caulescens* quite closely in habit and dimensions but has the floral bracts densely lepidote instead of glabrous.

6. **Tillandsia** (§ **Allardtia?**) **Werdermannii** Harms. Plant at least 5 dm. long, probably much longer: roots lacking (Werdermann!): stem procumbent, at least 2 dm. long, much branched, some of the branches or axillary shoots apparently breaking away and serving to propagate the species vegetatively: leaves densely polystichous, 15–20 cm. long, densely cinereous-lepidote, subpruinose; sheaths barely discernible, mostly less than 3 cm. long; blades suberect, narrowly triangular, 10–15 mm. broad at base, channeled, involute-subulate, rigid, often somewhat contorted: scape terminal, 20–30 cm. long or more, ca. 4 mm. thick, glabrous; its bracts erect, numerous, densely imbricate, lanceolate, acute or acuminate, 5–8 cm. long, subcoriaceous, nerved, appressed-lepidote: inflorescence simple and distichous, 25 cm.

long combined with the scape from which it is difficult to distinguish it in the extremely old material at hand, linear, ca. 2 cm. broad; rhachis flexuous, strongly flattened and angled, glabrous; floral bracts like the scape-bracts but glabrous, ca. 4 cm. long, 3–4 times as long as the internodes, much exceeding the sepals, erect, densely imbricate, completely concealing the rhachis, not at all carinate: flowers very short-pedicellate; sepals free, linear-lanceolate, broadly acute, 22–25 mm. long, glabrous; petals many and stamens and pistil aborted as apparent beginning of viviparous flower.—Terrestrial; Chile.—Harms in Notizbl. x. 218 (1928).—Pl. III, fig. 4.

CHILE: TACNA: above Tacna, alt. 800–1200 m., 1925, *Werdermann 717* (B, TYPE; G, Mun, FM, Mo).

A single flower found on the Gray specimen is quite evidently infertile, indicating that the species has adapted itself to its environment along the same lines as has *T. latifolia* in coastal Peru.

Werdermann's informative note made at the time of collection may be translated as follows: "Lying loose on the ground, without roots and with only last year's or isolated very young and undeveloped inflorescences. Forming large pure stands, so that the masses on the pure sand appear gray from a long distance."

7. **Tillandsia** (§ **Allardtia**) **Cardenasii** L. B. Smith (see p. 154). Caulescent, flowering plant 20–25 cm. high: stem up to 1 dm. long, simple: leaves erect or suberect, densely polystichous, up to 2 dm. long; sheaths ovate, 5 mm. long, glabrous, chartaceous; blades linear-triangular, filiform-acuminate, 8 mm. wide at base, densely villous-lepidote with basally produced cinereous scales, involute: scape erect, 1 mm. in diameter, glabrous, sulcate; scape-bracts lanceolate, exceeding the internodes, dark purple, appressed-lepidote, the lowest foliaceous-laminate: inflorescence slightly exceeded by the leaves, simple, densely 4–7-flowered, lanceolate in outline, complanate, 5 cm. long, 1 cm. wide; floral bracts like those of the scape but glabrous, densely imbricate, submembranaceous, not at all carinate, up to 27 mm. long, exceeding the sepals: flowers known only in immature or in fruiting condition, subsessile; sepals free, lanceolate, acuminate, up to 20 mm. long, glabrous, nerved; petals lingulate, lilac (Cardenas!); stamens about equaling the style, slightly shorter than the petals: capsule cylindric, short-beaked, about equaling the floral bracts. Pl. III, figs. 5–6.

BOLIVIA: CHUQUISACA: rocky places, Cerro Macho, alt. 2730 m., 1933, *Cardenas 491* (G, TYPE).

8. **Tillandsia** (§ **Allardtia**) **Geissei** Phil. Plant 22–60 cm. high

and probably up to nearly 1 m., acaulescent or very short-caulescent: roots present: stem simple, not over 5 cm. long: leaves polystichous, spreading, 1–3 dm. long, much shorter than the inflorescence, densely appressed-cinereous-lepidote throughout; sheath ovate, many times shorter than the blade and merging imperceptibly with it, the same color as the blade or with a faint brownish tinge; blade narrowly triangular, filiform-acuminate, 7–12 mm. broad at base, soft and relatively thin, usually twisted toward apex: scape terminal, erect, slender, up to 4 dm. long, equaling or exceeding the leaves, glabrous; its bracts numerous, densely imbricate, densely cinereous-lepidote, the lower foliaceous, the upper lanceolate, apiculate, tinged with red like the floral bracts: inflorescence simple and distichous or unequally bifurcate with a lateral spike 12 cm. long; primary bract like the scape-bracts, much shorter than the lateral spike; single or principal spike linear-lanceolate, acute, 8–17 cm. long, 6–14-flowered; rhachis sharply 4-angled, less than 2 mm. thick, slightly flexuous, glabrous; floral bracts erect, imbricate, about 3 times as long as the internodes, concealing the rhachis until after anthesis, lance-ovate, acute, 30–35 mm. long, exceeding the sepals, 12–14 mm. wide, sparsely cinereous-lepidote becoming glabrous with age, not at all carinate, nerved, uniformly chartaceous, brilliantly variegated with red, green and yellow: flowers subsessile; sepals free, lanceolate, obtuse, 25 mm. long, glabrous, thin; petals 30 mm. long, linear with blade scarcely distinct, obtuse, rose-purple; stamens included; ovary slenderly ovoid, stigma short: capsule cylindric, 3–4 cm. long.—Epiphytic; Chile.—R. A. Philippi in Gartenfl. xxxviii. 369, t. 1302, figs. II–IIf (1889); Rev. Hort. lxi. 388 (1889).

CHILE: ANTOFAGASTA: Dept. Taltal, on stems of *Cereus* on ridges in upper part of fertile belt, vicinity of Aguada de Miguel Diaz, ca. 24° 35′ S. lat., 1925, *I. M. Johnston 5320* (G); ATACAMA: on *Cereus*, near Caldera, 1887, *W. Geisse* (Chile, TYPE; phot. G).

It is rather surprising to find this species, with its thin flat leaves and apparent preference for epiphytism, in the arid regions of northern Chile, where types like *T. Werdermannii* are much more to be expected.

9. **Tillandsia** (§ **Allardtia**) **arequitae** André. Flowering plant up to 4 dm. high, often subpulvinate: roots present: stem conspicuous, usually branching several times, decumbent for most of its length, ends of the branches ascending: leaves numerous, erect to recurved, densely polystichous, not at all secund, up to 20 cm. long (Mez!) but generally not much more than half that length, densely cinereous-lepidote throughout, pruinose; sheaths indistinct, densely imbricate, making

the stem appear very stout; blades narrowly triangular, acuminate up to the abruptly acute pungent apex, 15 mm. broad, stout, rigid, keeled below, complicate toward apex: scape erect, conspicuous, ca. 1 dm. long, usually exceeding the leaves; its bracts densely imbricate, narrowly elliptic, acute, greenish stramineous, at least the lower ones lepidote: inflorescence always simple, lanceolate, acute, complanate, up to 10 cm. long without the petals, densely 6–12-flowered; rhachis flexuous, 4-angled, narrowly alate, glabrous; floral bracts erect, densely imbricate and concealing the rhachis, 3 times as long as the internodes, narrowly triangular-ovate, acute, 25–40 mm. long, exceeding the sepals, rather thin, glabrous, slightly nerved, greenish with stramineous nerveless margins, ecarinate: flowers subsessile; sepals linear-lanceolate, obtuse, 21 mm. long, submembranaceous, glabrous, equal, free; petals ca. 5 cm. long, white, odorless, claw linear, blade spreading, suborbicular, ca. 18 mm. wide, obscurely crenate or entire; stamens elongate, barely included or exserted from the throat of the corolla, shorter than the pistil, anthers linear, 7 mm. long; pistil exserted, ovary prismatic: capsule not known.—Terrestrial and epiphytic; Uruguay.—André ex Mez in DC. Mon. Phan. ix. 814 (1896); Herter, Florula Urug. 45 (1930); Harms in Engl. & Prantl, Nat. Pflanzenf. xv a. 119 (1930). *T. xiphioides* var. *arequitae* André in Rev. Hort. lxv. 156, cum icon. (1893).

URUGUAY: MINAS: *Arechavaleta 2613 bis; Gibert; Tweedie 1120* (Mez!); Cerro de Arequita, 1890, *André K 320* (K, TYPE; G, FM).

In Osten's herbarium there is a plant collected in Paraguari, Paraguay, by Rojas, which is very close to this species. However, the petals are blue and the scape very short, and Sr. Osten informs me that the data on the label is not wholly reliable. Consequently I am waiting for more material to appear before noting a range extension for *T. arequitae* or describing the Rojas plant as a novelty.

I am much indebted to Sr. Osten for a series of photographs illustrating this species in general growth and in detail.

10. **Tillandsia** (§ **Allardtia**) **xiphioides** Ker-Gawl. Flowering plant from 15 to over 30 cm. high: roots present: stem from very short to 15 cm. long, simple or few-branched: leaves numerous, polystichous but sometimes almost distichous, erect to spreading, more or less curved or contorted, up to 25 cm. long but often very much shorter, densely cinereous- or ferrugineous-lepidote throughout, pruinose; sheaths large, densely imbricate, making the stem appear 1–2 cm. thick, passing imperceptibly into the blade; blade narrowly triangular, subulate-acuminate, flat and up to 2 cm. wide at base:

scape from practically none to 12 cm. long but always much obscured by the upper leaves, erect; its bracts elliptic-oblong, densely imbricate and completely concealing the scape, thin, the lower ones caudate and lepidote, the upper apiculate and nearly or quite glabrous: inflorescence always simple and distichous, lance-oblong, acute, up to 12 cm. long without the petals, 2–10-flowered; rhachis up to 3 mm. thick, 4-sided, narrowly alate, flexuous, glabrous; floral bracts densely imbricate, usually several times longer than the internodes, lance-oblong, acute, up to 7 cm. long, much exceeding the sepals, ca. 14 mm. wide, submembranaceous, prominently nerved with a broad scarious nerveless margin, glabrous or sometimes the lower ones sparsely lepidote, stramineous or suffused with red or violet, ecarinate: flowers sessile, erect, up to 10 cm. long; sepals linear-lanceolate, acuminate, up to 42 mm. long, free, glabrous, submembranaceous, prominently nerved; petals white, fragrant, claw linear, blade broadly elliptic, obtuse, spreading, ca. 2 cm. wide, conspicuously crenate-serrate; stamens elongate, barely included or exserted from the throat of the corolla, shorter than the pistil and much shorter than the petals, filaments filiform, straight, anthers linear, 8 mm. long; pistil exserted, style slender, ovary slenderly prismatic: capsule stout, abruptly short-beaked, 3 cm. long.—Saxicolous and epiphytic; Bolivia, Uruguay and northern Argentina.—Ker-Gawl. in Bot. Reg. ii. t. 105 (1816); Spreng. Syst. ii. 23 (1825); R. & S. Syst. vii. 1200 (1830); Hook. in Bot. Mag. xcii. t. 5562 (1866); Benth. & Hook. Gen. iii. 670 (1883); Bak. Journ. Bot. xxv. 214 (1887); Brom. 164 (1889); Mez in DC. Mon. Phan. ix. 813 (1896); Kuntze, Rev. Gen. iii. 304 (1898); Hicken, Chloris Plat. 62 (1910); Memmler in Gartenwelt, xvii. 718 (1913); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 248 (1917); Herter, Florula Urug. 45 (1930); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 119 (1930); Castellanos, Brom. & Cact. in Physis, x. 90 (1930); Brom. Arg. iii., in An. Mus. Nac. Hist. Nat. B. A. xxxvi. 375 (1931); iv., in xxxvii. 509 (1933). *Anoplophytum xiphyoides* Beer, Brom. 254 (1857), nomen. *Tillandsia macrocnemis* Griseb. Symb. Argent. in Goett. Abh. xxiv. 332 (1879); Spegazzini, Fungi Argent. 322 (1899). *T. xiphoides* E. Morr. ex Wittm. in Engl. & Prantl, Nat. Pflanzenf. ii. Abt. 4, 57 (1888). *T. odorata* Gill. ex Bak. Journ. Bot. xxv. 214 (1887), in synonymy. *T. sericea* Hort. ex Bak. ibid. *T. suaveolens* Lem. ex Bak. ibid. *Phytarhiza xiphioides* E. Morr. ex Bak. ibid. *T. unca* Griseb. sensu Hicken, Physis, i. (1912), non Griseb. (1874). *T. Friesii* Mez sensu Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 501, t. 1 (1933), non Mez (1906).—FLOR DEL AIRE (Argentina).

BOLIVIA: Potosi: prov. Nor-Chichas, on rocks near San Antonio, 1931, *Cardenas 93* (G). URUGUAY: San José: on rocks, Sierra de Mahama, *Larriera* (Ost, phot. G). ARGENTINA: Jujuy: Volcan, 1927, *Castillon 6613* (Castellanos!); Salta: *Rodriguez 6610* (Castellanos!); Cafayate, 1913, *Rodriguez 1252* (G, BA); Tucuman: La Hoyada, 1920, *Schreiter 1377* (G, BA); Las Arcas, 1920, *Schreiter 1099* (Castellanos!); near Baco, dept. Trancas, alt. 900 m., 1920, *Venturi 1316* (Ost); Sierra de la Candelaria, dept. Trancas, alt. 950 m., 1924, *Venturi 2495a* (G); dept. Tafi, Colalao del Valle, 1931, *Schreiter 7176* (Castellanos! as *T. Friesii* emend.); Catamarca: Piedra Blanca, 1908, *Castillon 6612* (Castellanos!); Andalgalá, 1915, *Jörgensen 6611* (Castellanos!); 1916, *1105* (Castellanos!); Santiago del Estero: 1913, *Wagner* (Castellanos!); La Rioja: Los Llanos, 1895, *Bodenbender* (Castellanos!); Sierra Velasco near La Rioja, *Hieronymus & Niederlein 9* (Mez!); San Juan: 1904, *Spegazzini* (Castellanos!); Córdoba: near Córdoba, 1879, *Lorentz 123* (G, BM); *Hieronymus 912* (US, FM); *423; Kurtz 1153; 4822* (Mez!); 1891, *Kuntze* (NY); Rio Primero, Sierra de Córdoba, 1874, *Hieronymus* (NY); Dean Funes, 1916, *Sanzin 1156* (Ost); Los Paredones near Capilla del Monte, Sierra Chica, alt. 1000 m., 1918, *Osten 13465* (Ost); 1923, *Osten 17114* (Ost); Sierra Grande, Cerro Áspero, 1922, *Castellanos 1204* (Castellanos!); San Luis: Sierra del Morro, 1913, *Pastore* (Castellanos!); Mendoza: near Mendoza, 1825, *Gillies* (G, BM, Cam); 1879, *Miers 640* (BM); Cacheuta, 1913, *Sanzin 276* (Ost).

According to Castellanos all reports of this species from Buenos Aires are based on introduced material.

The type can not be located at Kew, the British Museum or Cambridge and it seems probable that no specimen was preserved. Fortunately the plate accompanying the original description is unmistakable.

11. **Tillandsia** (§ **Allardtia**) **diaguitensis** Castellanos. Plant much slenderer and more elongate than either *T. xiphioides* or *T. arequitae:* stem up to 6 dm. long, 5 mm. in diameter, simple or few-branched: leaves evenly and laxly polystichous along the stem or distichous (Castellanos!), 8–10 cm. long, densely cinereous-lepidote throughout, furfuraceous; sheaths elliptic, amplexicaul, ca. 13 mm. wide, imbricate, making the stem appear 7–10 mm. thick; blades erect to recurved, narrowly triangular, acuminate, ca. 6 mm. wide, strongly nerved when dry, channeled along the upper face: scape terminal, conspicuous, up to 8 cm. long; its bracts imbricate and concealing it, elliptic, acute, thin, stramineous, strongly nerved, lepidote toward apex: inflorescence always simple, spike lanceolate, acute, 4–9 cm. long, 14 mm. broad, densely 3–6-flowered; rhachis slender, nearly straight, glabrous, strongly sulcate; floral bracts imbricate, 2 to 3 times as long as the internodes, lanceolate, acute, 4–5 cm. long, much exceeding the sepals, chartaceous and strongly nerved with a scarious nerveless margin, glabrous, roseate: pedicels 3 mm. long; sepals oblong-lanceolate, acute, 32 mm. long, membranaceous, strongly nerved, glabrous, free: petals ca. 7 cm. long, white or bluish, fragrant,

claws linear, forming a tube well beyond the sepals, blades spathulate, minutely denticulate; stamens 51 mm. long including the 8 mm. long anthers, exserted from the throat of the corolla; pistil 55 mm. long, ovary 7 mm. long, stigma 3-parted: capsule equaling or shorter than the floral bracts.—Saxicolous and epiphytic; northwestern Argentina. —Castellanos, Brom. Arg. ii., in An. Mus. Nac. Hist. Nat. B. A. xxxvi. 55, t. 10 (1929); iv., in xxxvii. 501 (1933).

ARGENTINA: JUJUY: Volcán, 1920, *Castillon 7224* (hb. Castellanos, TYPE); SALTA: dept. San Carlos, Quebrada de Amblayo, 1927, *Schreiter 6585* (Castellanos!); TUCUMAN: dept. Tafi, Las Arcas to Tiopunco, 1917, *Schreiter 809* (Ost); Las Arcas, 1927, *Schreiter 5524* (Castellanos!); same, alt. 2000 m., *Venturi 8670* (G); dept. Trancas, Cadillal to Tapia, alt. 700 m., 1920, *Venturi 1395* (US).

Castellanos describes the leaves as distichous but illustrates them as polystichous. In all the material that I have seen so far they are far from distichous also.

12. **Tillandsia** (§ **Anoplophytum**) **argentina** C. H. Wright. Often pulvinate, flowering plant up to 13 cm. high: stem short but usually distinct, simple or few-branched, up to 8 cm. long (Mez!): roots present: leaves densely polystichous, often secund-curved, up to 13 cm. long but the lower ones much reduced; sheaths triangular, merging imperceptibly into the blades, thin, at least the lower half glabrous and lustrous; blades erect or suberect, very narrowly triangular or linear, abruptly acute, pungent, rigid, channeled above, obtusely carinate below, angular-subulate, 3–6 mm. wide: scape from practically none to 6 cm. long, exceeded by the leaves, erect or ascending, glabrous; its bracts imbricate and concealing it, lanceolate, acuminate, stramineous, chartaceous, strongly nerved, glabrous: inflorescence always simple, broadly lanceolate or oblanceolate, strongly complanate, up to 45 mm. long and 15 mm. wide, 4–7-flowered, glabrous throughout; rhachis nearly straight, strongly 4-angled; floral bracts lanceolate, acuminate, up to 25 mm. long, exceeding the sepals, subcoriaceous, even or somewhat nerved, ecarinate, red, sublustrous: flowers erect, subsessile; sepals narrowly lance-triangular, acuminate, 12–18 mm. long, free, subequal; petals narrow with scarcely distinct suberect to spreading blades, ca. 30 mm. long, obtuse, entire, bright rose-red; stamens ca. 20 mm. long, deeply included, shorter than the pistil, filaments thickened and transversely plicate, anthers linear, 5 mm. long; ovary subprismatic: capsule 20 mm. long, cylindric, beaked.—Saxicolous and epiphytic; northern Argentina.— Kew Bull. 60 (1907). *T. unca* Griseb. sensu Bak. Journ. Bot. xxv. 234 (1887); Brom. 165 (1889); Mez in DC. Mon.

Phan. ix. 812 (1896); Kuntze, Rev. Gen. iii. 304 (1898); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 248 (1917); Castellanos, Brom. Arg. i., in Com. Mus. Nac. Hist. Nat. B. A. ii. 144 (1925); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 119 (1930); Castellanos, Brom. Arg., iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 508 (1933), non Griseb. (1874).—Pl. II, figs. 5–7.

ARGENTINA: Jujuy: dept. Ledesma, Sierra de Calilagua, alt. 750 m., 1927, *Venturi 5359* (US); Salta: dept. Guachipas, Alemania, alt. 1300 m., 1929, *Venturi 9978* (G); Tucuman: dept. Capital, Barranca Colorada, alt. 550 m., 1920, *Venturi 993* (Ost, BA); dept. Famailla, Rio Leales, alt. 450 m., 1923, *Venturi 2494* (G); Rio Lules, alt. 450 m., 1923, *Schreiter 797 in part* (Ost); Tapia, Cadillal, alt. 500 m., 1918, *Schreiter 797 in part* (Ost); Tapia, 1920, *Venturi 1033* (US); Córdoba: Cosquin to Santa Maria, Sierra de Córdoba, *Hieronymus 346* (FM); Sierra de Córdoba, *Berg* (Mez!); *Hieronymus* (NY, BM); north of Cuesta de Copina, Sierra Achala de Córdoba, 1878, *Hieronymus* (NY); Desempeñadero to San Roque, 1881, *Hieronymus* (US, NY, phot. G); Ochoa, Punilla, 1903, *Stuckert* (K, type; phot. G); Los Paredones near Capilla del Monte, Sierra Chica, alt. 1000 m., 1918, *Osten 13464* (Ost); Rio Pintos, Sierra Chica, alt. 1000 m., 1918, *Osten 13492* (Ost); Catamarca: Cuesta de Chilca, *Lorentz 252* (Mez!).

Baker, Mez, Castellanos and Harms have all considered this species as identical with *T. unca* Griseb., but none of them cite the type of *T. unca* and I have not been able to locate it as yet either. However, there is ample evidence in the original description to prove that true *T. unca* is nearly related to if not identical with *T. pulchella* Hook.

Venturi 1315 from Barranca Colorado, Tucuman, combines the characters of *T. argentina* and of *T. ixioides*, which have both been collected from that locality. The hybridizing of *T. argentina* with a species of *Anoplophytum* and its possession of plicate filaments make it seem logical to include it in that section. Such action means that *Anoplophytum*, like *Allardtia* and *Platystachys*, must include both simple distichous and simple polystichous types of inflorescence and must be characterized by the form of its filaments.

13. **Tillandsia** (§ **Anoplophytum**) **incarnata** HBK. Plant attaining a length of 65 cm. and probably much more (no complete specimens have been seen in herbaria), growing in dense masses (André! Lehmann!): roots not noted, probably lacking: stem branching, attaining at least 4 dm.: leaves densely polystichous, 8–18 cm. long, densely cinereous-lepidote, scales appressed or slightly pruinose; sheath ovate, scarcely distinguishable from the blade and several times shorter, sometimes tinged with brown; blades suberect to spreading, narrowly triangular, filiform-acuminate, 10–17 mm. broad at base, usually involute toward apex: scape terminal, straight or slightly

curving, ca. 2 mm. thick at base, lepidote or glabrous, 1–4 dm. long, much exceeding the leaves; its bracts numerous, densely imbricate, elliptic, chartaceous, densely cinereous-lepidote, roseate, the lower ones with long filiform blades, the upper ones acute or apiculate: inflorescence simple and distichous, lanceolate, acute, 5–9 cm. long, 10–17 mm. wide, complanate, 5–12-flowered, often 1 or 2 sterile flowers at apex; rhachis nearly straight, sharply 4-angled, lepidote; floral bracts erect and imbricate or the lowest slightly divergent, 3–4 times as long as the internodes, elliptic, apiculate, 20–25 mm. long, exceeding the sepals, not at all carinate, chartaceous, densely appressed-lepidote, strongly nerved, roseate: flowers subsessile; sepals elliptic-lanceolate, acute, ca. 14 mm. long, prominently nerved, profusely lepidote, connate posteriorly for about half their length; petals narrowly elliptic, obtuse, 20–25 mm. long, erect or nearly so, rose; stamens distinctly shorter than the petals, filaments dilated above and transversely plicate, anthers 4–5 mm. long, subfiliform, acute, sagittate at base; pistil about equaling the stamens, ovary slenderly ovoid: capsule up to 25 mm. long, subprismatic, abruptly short-beaked, dehiscing to the base.—Terrestrial, saxicolous or epiphytic (André!); Colombia, Ecuador.—Nov. Gen. i. 291 (1816); Spreng. Syst. ii. 24 (1825); R. & S. Syst. vii. 1208 (1830); Dietr. Syn. ii. 1057 (1840); André in Belg. Hort. xxvii. 219 (1877); Wittm. in Engl. Bot. Jahrb. xi. 64 (1889); Bak. Brom. 170 (1889); André, Brom. André, 77 (1889); Mez in DC. Mon. Phan. ix. 809 (1896); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 119 (1930). *Platystachys incarnata* Beer, Brom. 264 (1857). *Tillandsia striata* Willd. ex R. & S. Syst. vii. 1209 (1830), in synon. *T. brevifolia* Bak. in Journ. Bot. xxv. 239 (1887).—Pl. II, figs. 8–10.

COLOMBIA: Norte de Santander: Pamplona, *Funck & Schlim 1479* (BM); between Mutiscua and Pamplona, alt. 2500 m., 1927, *Killip & Smith 19767* (G, US, NY); Cundinamarca: between Bogotá and La Mesa, *Goudot* (Mez!); Facatativa, alt. 2750 m., 1875, *André 604 in part* (K, NY); Salto de Tequendama, alt. 2500 m., 1876, *André 604 in part* (K, NY); 1925, *Schultze 71* (US); Quetame, alt. 100–500 m., 1930, *E. P. Arbelaez 4* (US); Bogotá, alt. 2640 m., *B. G. Amórtegui 175* (US); Nariño: La Galera Volcano, near Pasto, alt. 3200 m., 1876, *André 604 in part* (K). ECUADOR: Imbabura: banks of the Rio Chota, alt. 1670 m., 1876, *André 604 in part* (K, NY); Pichincha: banks of the Rio Guallabamba, 1802, *Humboldt & Bonpland* (HBK!); Valley of Turubamba, between Magdalena and Chillogallo, *Firmin 265* (US, FM); Leon: Cotopaxi, *Wagner 92* (Mez!); Tungurahua: near Ambato, 1802, *Humboldt & Bonpland* (HBK!); dry sterile valleys, near Riobamba, Ambato, Tacunga, Guallabamba, etc., alt. 1800–2300 m., 1880, *Lehmann 147* (US, BM); *147 a* (Mez!); Ambato, *Pearce* (K); same, alt. 2600 m., 1923, *Hitchcock 21705* (G, US, NY); Chimborazo: "province of Riobamba," *Rimbach 121* (G, US); Azuay: between Oña and Cuenca, alt. 2700–

3300 m., 1923, *Hitchcock 21610* (G, US, NY); INDEFINITE: 1855, *Couthouy* (G); interandine highland, alt. 2800 m., 1932, *Rimbach 78* (G).

Mez[1] cites *Humboldt & Bonpland 3138* from S. Felipe, yet a photograph of this number from Paris and another from Berlin-Dahlem disclose no locality at all on the label. The original description[2] reads: "Crescit ad fluvium Guallabamba et prope Hambato Quitensium, ..." Sprague[3] lists no S. Felipe in Humboldt's route in Colombia, the country where Mez cites it, but Sandwith[4] lists it in Peru far to the south of the proved range of *Tillandsia incarnata.* Thus there is every indication that Mez's citation is due to some misunderstanding.

It is impossible to tell now to which of the two localities in the original description the type should be assigned. Neither is it evident which of these is represented by the specimen at Paris or by that at Berlin-Dahlem.

As shown by *Rimbach 121*, *Tillandsia incarnata* has filaments that are dilated and transversely plicate near the apex, and for this reason I consider it a member of the section *Anoplophytum* in the same way that *T. argentina* is.

14. **Tillandsia** (§ **Platystachys**) **Ehrenbergiana** Kl. Flowering plant 10–20 cm. high: roots present: stem simple or branched, 3–5 cm. long, much exceeded by the leaves: leaves densely polystichous, up to 15 cm. long, densely cinereous-villous with fine scales which are produced basally into long narrowly triangular lobes; sheaths broadly elliptic, distinct from the blades, the lower part membranaceous, glabrous, strongly nerved; blades mostly spreading or reflexed, involute-subulate, filiform-acuminate, 3 mm. in diameter: scape terminal, erect or ascending, less than 1 mm. in diameter, strongly sulcate, glabrous; its bracts imbricate, involute, much exceeding the internodes, lanceolate, acuminate, thin, strongly nerved, roseate, lepidote, the lower laminate: inflorescence always simple, elliptic, terete to strongly complanate, 35 mm. long, 16 mm. wide, densely 3–8-flowered; rhachis slender, nearly straight; floral bracts imbricate and concealing the rhachis, 3 to 4 times as long as the internodes, lanceolate, acute, 26 mm. long (Mez!), much exceeding the sepals, 8 mm. wide, membranaceous, strongly nerved, roseate, puberulent-lepidote, the upper half distinctly carinate: flowers subsessile; sepals lanceolate, acuminate, up to 17 mm. long, 5 mm. wide, carinate,

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[1] Mez in DC. Mon. Phan. ix. 810 (1896).
[2] HBK. Nov. Gen. i. 291 (1816).
[3] Kew Bull. 1926. 23 (1926).
[4] Kew Bull. 1926. 187 (1926).

membranaceous, strongly nerved, lepidote, subfree; petals tubular-erect, probably yellow (Mez!); stamens and pistil exserted (Mez!), ovary ellipsoid: capsule cylindric, acute, 25 mm. long.—Epiphytic; central Mexico.—Kl. ex Bak. Brom. 169 (1889). *T. Ehrenbergii* Kl. ex Beer, Brom. 264 (1857), nomen; Mez in DC. Mon. Phan. ix. 727 (1896); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 118 (1930). *Platystachys Ehrenbergii* Beer, Brom. 264 (1857), nomen.—Pl. III, figs. 7–8.

MEXICO: SAN LUIS POTOSI: near San Luis Potosi, alt. 2000–2700 m., 1878, *Parry & Palmer 872* (G, US, Mo); GUANAJUATO (?): Jaral, *Schumann 1513* (US); HIDALGO (?): Rugla, *Ehrenberg 860* (BM, TYPE; G); FEDERAL DISTRICT: Valley of Mexico City, *Schmitz 228* (BM); INDEFINITE: *Christy* (Mez!).

T. Ehrenbergiana is the first name for this species to be accompanied by a description and so must stand.

15. **Tillandsia** (§ **Platystachys**) **Schiedeana** Steud. Flowering plant up to 4 dm. long, but usually not much more than 2 dm., often pulvinate: roots present: stem 5–20 cm. long, simple or few-branched: leaves polystichous, varying greatly in density, up to 25 cm. long, densely cinereous- or ferrugineous-lepidote, scales appressed near apex of leaf, pruinose below; sheaths suborbicular, large, densely imbricate and making the stem appear very stout, at least the margin hyaline, glabrous only where covered; blades very narrowly triangular, filiform-acuminate, involute-subulate: scape terminal, erect, shorter than the leaves; its bracts imbricate and concealing it, the lower foliaceous, the upper thinner and usually roseate but usually with a distinct filiform lamina also: inflorescence always simple, distichous or sometimes polystichous at base (Mez!), lanceolate, acuminate at both ends, terete, up to 7 cm. long and 8 mm. in diameter but often less than half as large, densely few-flowered; rhachis nearly straight, slender, strongly sulcate, glabrous; floral bracts densely imbricate and wholly concealing the rhachis, 2–3 times as long as the internodes, elliptic-lanceolate, obtuse or the basal ones minutely apiculate, ca. 30 mm. long and 10 mm. wide, much exceeding the sepals, membranaceous, roseate, strongly nerved, the lower ones appressed-lepidote, the upper ones often glabrous: flowers sessile, up to 46 mm. long; sepals lanceolate, acute, up to 20 mm. long, subcoriaceous, glabrous, even or few-nerved, the posterior ones usually much connate; petals tubular-erect, yellow; stamens and pistil exserted, ovary ellipsoid: capsule cylindric, up to 45 mm. long.—Epiphytic; Mexico and the West Indies to Colombia and Venezuela.—Nomencl. ed. 2, ii. 688 (1841). *T. vestita* Ch. & Schdl. in Linnaea, vi. 52 (1831), non Willd. (1830),

nec Benth.; Schdl. in Linnaea, xviii. 423 (1844); Hemsley, Biol. Centr.-Am. iii. 323 (1884); Bak. in Journ. Bot. xxv. 238 (1887); Brom. 170 (1889); Millspaugh, Field Mus. Pub. i. 12 (1895); Mez in DC. Mon. Phan. ix. 728 (1896); Standley & Calderon, Lista Prelim. Pl. El Salvador, 47 (1925); Standley, Field Mus. Pub. iii. 222 (1930); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 118 (1930). *T. flavescens* Mart. & Gal. in Bull. Acad. Brux. x. pt. 2, 118 (1843). *T. caerulea* HBK. sensu Griseb. in Goett. Nachr. 14 (1865), non HBK. *T. Grisebachii* Bak. in Journ. Bot. xxv. 305 (1887); Brom. 188 (1889). *T. Eggersii* Bak. Brom. 170 (1889).—Xeen (Yucatan); Gallito; Chivito (Salvador).—Pl. III, fig. 9.

MEXICO: Baja California: 1886, *McLellan* (US); San Luis Potosi: near Rascon, 1905, *Palmer 684* (US); Sinaloa: near Labradas, 1925, *Ferris & Mexia 5121 A* (DH); Vera Cruz: Actopan to Jalapa, 1829, *Schiede & Deppe* (B, type; BM); Orizaba, *Botteri 329* (G, US); 1855, *Mueller 1239* (G); 1866, *Bourgeau 2103 in part* (G); 1867, *Bilimek 425* (G); 1885, *Gray* (G); 1894, *Nelson 50 c* (US); 1905, *Purpus 1254* (G, FM, Mo); Cordoba, 1866, *Bourgeau 2103 in part* (G, US); 1884, *Carruthers* (BM); Fortin, 1883, *Kerber 295* (US, BM); near Jalapa, alt. 1200–1300 m., 1899, *Pringle 7793* (G, US); *8063* (G, US, FM, Mo, S, BM); Zacuapan, 1909, *Purpus 3764* (G, US, NY, FM, Mo, UCal, BM); 1919, *Purpus 8216* (UCal); *8221* (G, US, Mo); *8222* (G, US, NY, Mo); Nayarit: Pedro Paulo, 1897, *Rose 3324* (US); Hidalgo: Tatipan to Yahualica, alt. 300–900 m., 1891, *Maury 5956* (G); Jalisco: near Zapotlan, 1893, *Pringle 4376* (G, US, FM, Mo, S, BM); Puebla: valley of the Rio Necaxae near Huauchinango, alt. 1100 m., 1932, *Fröderström & Hultén 826* (S); Morelos: near Cuernavaca, alt. 1600 m., 1898, *Pringle 6860* (G, US, FM, Mo, S, BM); Oaxaca: Totolapa to San Carlos, alt. 1000–1200 m., 1895, *Nelson 2544* (G, US); below Jayacatlan, alt. 1100 m., 1895, *L. C. Smith 550* (G); Tabasco: Tenosique, alt. 60 m., 1892, *Beristain 8014* (G); Campeche: Tuxpeña, 1932, *Lundell 1383* (FM); Yucatan: *Johnson 84* (Mez!); *Gaumer 24422* (G, FM); Merida, 1864, *Schott 161* (BM, FM); Izamal, 1885, *Gaumer 427* (G, FM, Mo, US); 1906, *Greenman 402* (G, FM); Silam, 1885, *Gaumer 664* (G, US, FM, Mo); Quintana Roo: Chichankanab, *Gaumer 1767* (G, US, FM, Mo, DH, S, BM, BA); *1914* (G, US, FM, Mo, S). BRITISH HONDURAS: Toledo, 1907, *Peck 944* (G); El Cayo, 1931, *Bartlett 12906* (G); 1933, *Chanek 115* (G); Rio Grande, 1933, *Schipp S 455* (G, FM). GUATEMALA: Peten: Tikal, 1931, *Bartlett 12651* (G); Vaxactun, 1931, *Bartlett 12287* (G); La Libertad, 1933, *Lundell 2517*, *2534* (G); *2592*, *3929* (Mich); Izabal: near Quirigua, alt. 75–225 m., 1922, *Standley 24218* (G, US, Mo, S); *24476* (G, US); *24606* (G, US, FM, Mo); Zacapa: Gualan, alt. 130 m., 1905, *Deam 211* (G); Guatemala: Sanarate, 1905, *Kellerman 4731* (US); Mt. San Antonio, alt. 1465 m., 1906, *Kellerman 5910* (US); Jalapa: Jalapa, 1908, *Kellerman 7867* (FM); Amatitlan: Pacaya, 1890, *J. D. Smith 1958* (G, US); Moran, alt. 1205 m., *Kellerman 4898* (US). SALVADOR: Santa Ana: near Santa Ana, alt. 655–900 m., 1922, *Standley 20411* (G, US); Ahuachapán: Sierra de Apaneca near Finca Colima, 1922, *Standley 20210* (G, US, S); Sonsonate: near Izalco, 1922, *Standley 22179* (G, US); near Sonsonate, alt. 220–300 m., 1922, *Standley 21772* (G, US); San Salvador: Tonacatepeque, 1921, *Calderon 217* (US); near San Salvador, 650–850 m., 1922, *Standley 22673* (G, US); 1923, *Calderon 1506* (US). HONDURAS: Cortez: Lake Yojoa, alt. 700 m., 1934, *Yuncker 4901* (FM). NICARAGUA: *Rothschuh 93* (Mez!); *Wright* (G, US); Chinandega: Realejo, 1903, *C. F. Baker 2086* (G, US, Mo, S);

Managua: southwest slopes of Santiago Volcano, near Masaya, alt. 300–480 m., 1923, *Maxon 7673* (US); near Managua, 1932, *Garnier 682* (US); *781* (G, US). COSTA RICA: *Oersted* (Mez!); Alajuela: El Coyolar, alt. 240 m., 1924, *Standley 39997*, *40075*, *40078* (US); San José: La Verbena near Alajuelita, alt. 1000–1200 m., 1898, *Tonduz 8953* (US, Bo); 1924, *Standley 32229* (US); Las Pavas, alt. 1070 m., 1924, *Standley 36108* (US); Cartago: Finca Las Concavas, alt. 1200–1300 m., 1925, *Standley 41527* (US); Cartago, alt. 1450 m., 1909, *Biolley 17364* (US); lower Rio Turrialba, 1925, *Stork 2450* (FM). CUBA: Pinar del Rio: near Sumidero, *Shafer 13822* (US, FM); Santa Clara: Trinidad Mountains, 1910, *Britton, Earle & Wilson 4840* (G, US); Pitajones, 1912, *Shafer 12190* (US, Mo); San Blas, La Sierra, alt. 200–330 m., 1930, *Jack 8040* (G, US, FM, S); 1931, *8207* (US); Oriente: Yara to Manzanillo, 1912, *Shafer 12366* (US). JAMAICA: *Bertero; Harris 5223* (Mez!). HAITI: Presqu'ile du Nord-Ouest, Port-de-Paix, near Cordier, 1925, *Ekman 3922* (US); near Anse Galette, Gonave Is., 1920, *Leonard 3116* (US); Dept. du Nord, near St. Raphael, alt. 350 m., 1925, *Leonard 7720* (G, US); Dept. l'Artibonite, near Gros Morne, alt. 235 m., 1926, *Leonard 10017 b* (US); near Mole St. Nicolas, 1929, *Leonard 13306* (US). SAN DOMINGO: *Bertero 463* (Mo); *Picarda 180* (Mez!); Llanos de San Rafael, 1887, *Eggers 1806* (K, type of *T. Eggersii;* BM, US); Prov. Barahona, Duvergé, 1911, *Fuertes 894* (G, US, BM); Azua, 1913, *Rose, Fitch & Russell 3893* (US); Prov. Monte Cristy, Dist. Moncion, 1929, *Valeur 148* (US, FM, Mo, S); same, alt. 300–400 m., 1931, *Valeur 794* (US, S). VENEZUELA: near Biscaina, alt. 1000 m., *Fendler 1533* (K, type of *T. Grisebachii*); Aragua: Maracay, *Vogl 1075* (Mun); Merida: San Juan to El Vegon, 1928, *Pittier 12852* (US, Mo, Mun). COLOMBIA: Magdalena: Santa Marta, alt. 260 m., 1898–9, *H. H. Smith 2348* (G).

After being in constant use for over one hundred years, *Tillandsia vestita* has to be replaced by *T. Schiedeana* because of an earlier homonym.

16. **Tillandsia** (§ **Platystachys**) **albida** Mez & Purpus. Flowering plant up to 4 dm. high: stem elongate, much branched: leaves densely polystichous, 12 cm. long, densely pale cinereous-lepidote; sheaths merging imperceptibly into the blades; blades suberect to squarrose, narrowly triangular, long-acuminate, channeled above but not convolute: scape terminal, erect, short but exceeding the leaves; its bracts densely imbricate, bright red, white-lepidote: inflorescence 13 cm. long, 3 cm. wide, laxly 6-flowered; rhachis undulate, angled, glabrous, bright red; floral bracts erect, not at all imbricate nor concealing the rhachis, elliptic, obtuse, up to 21 mm. long, coriaceous, nearly or quite even with a hyaline margin, ecarinate, especially the lower ones appressed-lepidote: flowers erect, with short stout pedicels, 37 mm. long without the genitalia; sepals obtuse, 20 mm. long, coriaceous, glabrous, even, pale green; petals greenish white, obtuse, tubular-erect; stamens and pistil 5 mm. longer than the petals.—Central Mexico.—Mez & Purpus in Fedde Rep. Spec. Nov. xiv. 248 (1916).

MEXICO: Hidalgo: near Ixmiquilpan, *Purpus* (hb. Mez, type).

The material was originally received at Darmstadt and cultivated there, then sent to Königsberg where Mez studied it.

Maury 5748 from Cañadade Meztitlan, Hidalgo, Mexico, (FM, G), has nearly the same habit as this species, but its inflorescence is so imperfect that it can not be identified with certainty unless compared with the type, which I have not examined.

17. **Tillandsia** (§ **Platystachys**) **Funckiana** Bak. Plant up to 3 dm. long, pulvinate: roots present: stem branching, 2–3 mm. in diameter: leaves very densely polystichous, scarcely more than 5 cm. long, densely lepidote throughout with appressed cinereous or brownish scales; sheaths distinct, triangular-ovate, ca. 5 mm. long; blades erect to recurved, linear, 1–2 mm. broad at base, filiform-acuminate, strongly keeled below: scape none: inflorescence terminal, consisting of a single flower or rarely two; floral bract lance-oblong, acute, membranaceous, 1-nerved, glabrous, not more than half as long as the sepals: sepals elliptic-ovate, obtuse, ca. 15 mm. long, chartaceous, even, glabrous, free; petals tubular-erect, up to 44 mm. long, red: stamens and pistil exserted.—Terrestrial and epiphytic; Venezuela. —Bak. Brom. 196 (1889); Mez in DC. Mon. Phan. ix. 730 (1896); R. Knuth in Fedde Rep. Spec. Nov. Beiheft, xliii. 189 (1927).—Pl. IV, fig. 1.

VENEZUELA: MERIDA: Laderas de San Pablo near Merida, alt. 500–700 m., *Funck & Schlim 1258* (BM, TYPE; Bo, Gen, P, Leningrad); El Morro, alt. 1750 m., 1911, *Jahn 78* (US); Laderas de San Pablo, Rio Chama, alt. 600 m., 1922, *Jahn 1088* (G, US, NY); between Estanques and Puente Real, San Juan to El Vegon, alt. 400–1100 m., 1928, *Pittier 12846* (US, NY).

Baker described the inflorescence as 2–3-flowered, while actually it is 1- or very rarely 2-flowered. This discrepancy is probably due to his drawing his description partly from *Anoplophytum brachypodium* which he included as nearly allied. Neither does there seem to be any evidence of the large size of the floral bract, 47 mm., as recorded by Mez. Mr. Dandy in a recent letter confirms my opinion that there is no such large bract to be found on the type at the British Museum.

18. **Tillandsia** (§ **Phytarrhiza**) **paleacea** Presl. Flowering plant 1–7 dm. long: roots present at least in the early stages of development: stem up to 35 cm. long and probably much more, much branched, appearing stout because of the leaf-sheaths: leaves polystichous in relatively few rows and rather widely spaced so that the blade and the upper half of the sheath are clearly visible, cinereous, often becoming fuscous with age, densely tomentose-lepidote; sheaths large, broadly ovate or elliptic, glabrous except on the upper half outside; blades abruptly spreading, irregularly contorted in most cases, narrowly triangular, 4–6 mm. broad at base, involute-subulate, up to

12 cm. long: scape slender, erect, from very short to over 15 cm. long, glabrous or nearly so; its bracts mostly equaling or exceeding the internodes, narrowly elliptic, apiculate, lepidote, the lower ones filiform-laminate: inflorescence always simple and distichous, narrowly lanceolate, acute, complanate, up to 5 cm. long, densely 1–12-flowered; rhachis strongly angled, glabrous, practically straight or slightly geniculate; floral bracts imbricate, about 3 times as long as the internodes, ovate or elliptic, 12–17 mm. long, varying from slightly longer to slightly shorter than the sepals, not at all carinate, prominently nerved, more or less lepidote when young, becoming glabrous with age: flowers subsessile; sepals lanceolate, 10–17 mm. long, free, glabrous; petals with narrow claw and large suborbicular spreading blue or violet blade; stamens deeply included, exceeding the pistil: capsule cylindric, ca. 2 cm. long.—Presl, Rel. Haenke. i. 125 (1827); R. & S. Syst. vii. 1203 (1830); Gay, Fl. Chil. vi. 16 (1853); Phil. An. Univ. Chile, lix. 323 (1881), Cat. Pl. Chil. 279 (1881); Bak. Journ. Bot. xxv. 279 (1887); Brom. 166 (1889); Mez in DC. Mon. Phan. ix. 884 (1896); L. B. Smith, Contrib. Gray Herb. civ. 81, t. 2 (1934). *T. fusca* Bak. in Journ. Bot. xvi. 240 (1878); xxv. 213 (1887); Brom. 161 (1889); Mez in DC. Mon. Phan. ix. 727 (1896). *T. scalarifolia* Bak. in Journ. Bot. xxv. 235 (1887); Brom. 165 (1889); Mez in DC. Mon. Phan. ix. 857 (1896); Mez ex Bruns in Mitt. Inst. Allg. Bot. Hamburg, viii. 41 (1929); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 120 (1930); F. L. Herrera, Est. Fl. Dep. Cuzco, 78 (1930). *T. Schenckiana* Wittm. in Engl. Bot. Jahrb. xi. 63 (1889); Bak. Brom. 165 (1889). *T. chilensis* Bak. Brom. 166 (1889); Mez in DC. Mon. Phan. ix. 857 (1896). *T. lanata* Mez in Bull. Herb. Boiss. ser. 2, v. 109 (1905); Weberbauer, peruan. Anden in Engl. & Drude, Veg. d. Erde, xii. 81 (1911). *T. favillosa* Mez in Fedde, Rep. Spec. Nov. iii. 43 (1906); Weberbauer, peruan. Anden in Engl. & Drude, Veg. d. Erde, xii. 81 (1911); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 120 (1930).

COLOMBIA: Cauca or Tolima (?): near La Plata, alt. 1000 m., 1882, *Lehmann XXVII* (Bo, type of *T. Schenckiana;* BM, phot. G); same, *2234* (Mez!). PERU: San Martin: near Moyobamba, *Steubel 62 b* (Mez!); Lima: Obrajillo, *Brackenridge in Wilkes Expedition* (K, type of *T. fusca;* G, US); near Matucana, alt. 2370 m., *Weberbauer 1697* (B, type of *T. lanata;* phot. G); Chosica, alt. 1000 m., 1923, *Macbride 2879* (G, US, FM); Cuzco: prov. Urubamba, near Ollantaitambo, alt. 2800–3000 m., 1905, *Weberbauer 4933* (B, type of *T. favillosa;* phot. G); 1915, *Cook & Gilbert 554* (US); 1925, *F. L. Herrera 702; 801* (US); Torontoy, Urubamba Valley, alt. 2400 m., 1915, *Cook & Gilbert 1774* (US); Arequipa: Cachendo, alt. ca. 1000 m., *Guenther & Buchtien 357* (Mez!). BOLIVIA: La Paz: La Granja, alt. 2600 m., 1923, *Bro. Julio 158* (US, BM); Indefinite: *Pentland* (K, type of *T. scalarifolia;* phot. G). CHILE: without further locality, *Haenke* (Prague, type; phot. G); northern Andes of Chile (Baker!), *Gay* (P, type of *T. chilensis;* phot. G).

In spite of the addition of *T. chilensis* to the synonymy of *T. paleacea* it is still extremely doubtful whether the species occurs in Chile. Gay said of *T. paleacea:* "Dudamos tambien que Haenke haya encontrado esta planta en Chile; á nuestro modo de ver, este país no incluye ninguna especie de Tillandsia con flores en espiga."

In view of this statement and of the fact that the label on the type of *T. chilensis* is merely a form-label with "Chili" printed on it and no further data written in, it seems likely that Gay really collected the plant during his stay at either Lima or Cuzco.

19. **Tillandsia** (§ **Phytarrhiza**) **arhiza** Mez. Roots wholly lacking (Balansa!): stem up to 6 dm. long, stout: leaves densely polystichous, ca. 2 dm. long, ferruginous-cinereous, densely and coarsely pruinose- or tomentose-lepidote; sheaths elongate, broadly elliptic, amplexicaul, ochreiform, glabrous inside and below the middle outside; blades very narrowly triangular, 7–9 mm. wide, channeled, involute-subulate above the middle, filiform-acuminate, erect or diverging, recurving toward apex: scape slender, erect, exceeding the leaves, glabrous; its bracts erect, tubular-involute, equalling or exceeding the internodes, sublanceolate, acute or apiculate, densely lepidote: inflorescence depauperate-compound in the type with two much reduced lateral spikes but more often simple and distichous; axes glabrous; primary bracts like the scape-bracts, lepidote, much shorter than the axillary spikes; single or principal spike linear or lanceolate in outline, up to 75 mm. long, 10 mm. wide, densely 6–12-flowered; rhachis strongly angled, slightly flexuous; floral bracts strictly erect, often closely involute about the sepals, not noticeably imbricate, narrowly elliptic, apiculate, ca. 15 mm. long, from distinctly shorter than to slightly exceeding the sepals even on the same plant, chartaceous, glabrous or the lowest scantly lepidote, prominently nerved: flowers with a very short stout pedicel; sepals elliptic, acute or obtuse, ca. 12 mm. long, 5 mm. wide, even, glabrous, coriaceous, subequally connate up to about 3 mm.; petals violet, ca. 23 mm. long, blades suborbicular, stamens deeply included, exceeding the pistil, anthers linear, acute; ovary elongate, prismatic, abruptly contracted into the style: capsule cylindric, abruptly acute.—Saxicolous; Paraguay.—Mez in DC. Mon. Phan. ix. 855 (1896); Chod. & Vischer, Vég. Par. in Bull. Soc. Bot. Genève, ser. 2, viii. 202–64, t. 98–100, 104 (1916); Hassler in Ann. Cons. & Jard. Bot. Genève, xx. 330 (1919); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 120 (1930). *T. rupestris* Mez in DC. Mon. Phan. ix. 856 (1896); Plant. Hassl. ii. 259 in Bull. Herb. Boiss. ser. 2, iii. 1037 (1903); Chod. &

Vischer, Vég. Par. in Bull. Soc. Bot. Genève, ser. 2, viii. 202–64, t. 87–9, 91 (1916). *T. rupestris* var. *pendens* Chod. & Vischer, ibid. 229, t. 91–2 (1916). *T. arhiza* var. *rupestris* Hassler in Ann. Cons. & Jard. Bot. Genève, xx. 331 (1919); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 120 (1930).—Pl. III, figs. 2–3.

PARAGUAY: on granite rocks at the summit of Cerro d'Acahy, near Paranaguari, *Balansa 4747* (P, TYPE; phot. G); on granite rocks of Cerro San Thomas near Paranaguari, *Balansa 4746* (Bo, P, type of *T. rupestris;* phot. G); slopes of San Thomas, *Hassler 1000* (K, phot. G).

20. **Tillandsia** (§ **Phytarrhiza**) **caerulea** HBK. Plants up to 25 cm. long, sometimes in dense masses: roots lacking: stem simple, 4–6 cm. long: leaves polystichous, 10–15 cm. long, densely furfuraceous or tomentose-lepidote, cinereous; sheaths ovate, barely over 1 cm. long; blades mostly spreading or reflexed, filiform-subulate, involute, soft, more or less flexuous or contorted, ca. 2 mm. broad at base: scape terminal, erect, up to 15 cm. long, ca. 1 mm. in diameter at base, lepidote; its bracts involute, erect, shorter than the internodes at least as regards the sheathing portion, densely lepidote, filiform-laminate: inflorescence always simple and distichous, 4–7 cm. long, laxly 3–7-flowered with the apical one sterile; rhachis very slender, subterete, lepidote, strongly offset opposite the base of each flower but otherwise only slightly flexuous; floral bracts closely enfolding the calyx, not at all imbricate nor concealing the rhachis, diverging from the rhachis at an angle of about 45°, slightly longer than the internodes, elliptic, acute, ca. 15 mm. long, 7 mm. broad, equalling or exceeding the sepals, chartaceous, prominently nerved, lepidote, sometimes dark purple: flowers sessile; sepals lanceolate, acute, mucronate, prominently nerved, equally short-connate, 12 mm. long, 4 mm. wide, glabrous, thin; petals 20 mm. long, claw narrow, blade subrhombic, 7 mm. wide, blue; stamens ca. 8 mm. long, deeply included, exceeding the pistil, anthers 3 mm. long, linear, dorsifixed near base; ovary stout, subprismatic, about the same length as and but little thicker than the style.—Epiphytic; Ecuador, Peru.—Nov. Gen. i. 291 (1816); R. & S. Syst. vii. 1209 (1830); Bak. Journ. Bot. xxv. 305 (1887); Brom. 166 (1889); Mez in DC. Mon. Phan. ix. 861 (1896). *T. squamulosa* Willd. ex R. & S. Syst. vii. 1209 (1830), in synon. *Diaphoranthema squamulosa* Beer, Brom. 266 (1857).—Pl. IV, figs. 3–4.

ECUADOR: AZUAY: between Oña and Cuenca, alt. 2700–3300 m., 1923, *Hitchcock 21585* (US); LOJA: between El Tambo and La Toma, alt. 1000–2200 m., 1923, *Hitchcock 21334* (G, US). PERU: PIURA: Rio Macará, *Humboldt & Bonpland 3442* (B, P, TYPE; phot. G); Sancicito, about 40 miles north of

Sallana, Negritos, *O. Haught F-11* (FM); Amotape Mts., 1926, *O. Haught 128* (US).

What the Mexican citations of Sochipala and Sopilote in the original description of this species stand for I have been unable to ascertain. They can scarcely represent the same species.

The petal-blade of *T. caerulea* is much more like that of typical section *Phytarrhiza* than it is like that of *Diaphoranthema*, and accordingly I have transferred the species to *Phytarrhiza*.

21. **Tillandsia** (§ **Phytarrhiza**) **crocata** (E. Morr.) Bak. Plant 15–35 cm. long: roots present: stem simple or few-branched, up to 2 dm. and more long (Mez!): leaves distichous, 1–3 dm. long, densely tomentose-lepidote with fine reflexed scales; sheaths broadly ovate, glabrous except for the upper half outside; blades spreading or recurving, linear, long-acuminate, involute-subulate, 2–5 mm. in diameter at base: scape terminal, erect or nearly so, slender, 5–15 cm. long, retrorse-tomentose like the leaves, naked or with a single leaf-like bract: inflorescence always simple and distichous, lanceolate or elliptic, acute, 1–4 cm. long not counting the petals or capsules, densely 2–6-flowered with the terminal flower sometimes sterile; floral bracts imbricate, 2–5 times as long as the internodes, ovate, acuminate, up to 2 cm. long, about equalling the sepals, densely tomentose-lepidote: flowers very short-pedicellate, fragrant (Lindman!); sepals sublanceolate, broadly acute or obtuse, thin, prominently nerved, densely appressed-lepidote except in extreme age; petals up to 2 cm. long; blade suborbicular, obtuse, 6–8 mm. broad, bright yellow; stamens deeply included, exceeding the pistil: capsule cylindric, ca. 3 cm. long.—Terrestrial and epiphytic; Bolivia, Brazil, Uruguay, Argentina.—Bak. in Journ. Bot. xxv. 214 (1887); Brom. 163 (1889); Mez in Mart. Fl. Bras. iii. pt. 3, 607 (1894); Mez in DC. Mon. Phan. ix. 860 (1896); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 120 (1930); L. B. Smith in Ostenia, 361 (1933). *Phytarrhiza crocata* E. Morr. in Belg. Hort. xxx. 87 (1880). *T. Mandonii* E. Morr. ex Mez in DC. Mon. Phan. ix. 871 (1896); Ann. Cons. & Jard. Bot. Genève, xx. 334 (1919).—Pl. IV, figs. 21–22.

BOLIVIA: La Paz: prov. Larecaja, between S. Pedro and Coaconi, alt. 2650 m., 1861, *Mandon 1180* (K, type of *T. Mandonii;* BM, G, S). BRAZIL: Paraná: Capão Grande, Villa Velha, alt. 875 m., 1904, *Dusén 4284* (S, MN Rio); Villa Velha, 1910, *Dusén 9238* (S, G, US); Rio Grande do Sul: on little island in the mouth of the Rio Jacuhy, *Tweedie 427* (K, phot. G); Porto Alegre, Morro de Santa Theresa, 1893, *Golland in hb. Lindman* (S); Indefinite: 1879, *Lietze* (type; represented by one of the Morren Icones in hb. Kew, not known whether specimen still exists). URUGUAY: Mercedes: Rincon del Cololo, 1893, *Osten 3055* (Ost); Indefinite: *Miers 1367* (BM). ARGENTINA: Entre Rios: Concepcion del Uruguay, 1882, *Hieronymus* (S).

Tillandsia Mandonii was based on very old and weathered material. The only character in its description to distinguish it from *T. crocata* is the supposedly glabrous sepals, but both the Mandon and Miers collections show some scales still left on the sepals.

22. **Tillandsia** (§ **Phytarrhiza**) **bandensis** Bak. Plant 1–2 dm. long: roots present: stem much branched with the branching largely in a single plane, 4–6 cm. long: leaves densely distichous, 5–7 cm. long, densely pruinose- or tomentose-lepidote, cinereous to fuscous; sheaths broadly ovate, ca. 1 cm. long, glabrous except for the upper half outside; blades suberect to spreading, linear-subulate, involute, long-acuminate, 1–2 mm. in diameter at base: scape terminal, erect or decurved, up to 9 cm. long, ca. 0.5 mm. in diameter, sulcate, lepidote at least below; its bracts 1–2, remote, much shorter than the internodes, elliptic, the upper acute or apiculate and usually glabrous, the lower usually filiform-laminate and appressed-lepidote: inflorescence always simple and distichous, linear-lanceolate, 2–3 cm. long and 3–5 mm. wide not counting the petals, 2–4-flowered; rhachis very slender, slightly flexuous, excavated next the flowers, glabrous; floral bracts remote, not at all imbricate, equaling or slightly longer than the internodes, ovate-elliptic, acute, membranaceous, more or less prominently nerved, 9–12 mm. long, the lower ones equaling or somewhat shorter than the sepals and sometimes scantly lepidote, the upper ones much shorter than the sepals and glabrous: flowers strictly erect and appressed to the rhachis; pedicel very short, obconic; sepals subelliptic, acute, 8–10 mm. long, 2.5–3 mm. broad, thin, prominently nerved, glabrous, equally subfree; petals 15–16 mm. long, claw narrow, blade distinct, broadly elliptic or obovate, 5 mm. long, 6 mm. broad, blue or violet; stamens deeply included, exceeding the pistil, anthers linear; ovary subprismatic, passing gradually into the short style: capsule cylindric, ca. 2 cm. long.—Epiphytic; Bolivia, Paraguay, Uruguay, Argentina.—Bak. in Journ. Bot. xxv. 234 (1887); Brom. 165 (1889); Kerr, Bot. Pilcom. in Trans. & Proc. Edinb. Bot. Soc. xx. 73 (1894); Mez in DC. Mon. Phan. ix. 858 (1896); Hassler, Flor. Pilcom. in Trab. Mus. Farmac. B. A. xxi. 42 (1909); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 242 (1917); Herter, Florula Urug. 45 (1930); L. B. Smith, Not. Brom. in Ostenia, 362 (1933); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 498 (1933). *T. quadriflora* Bak. Brom. 163 (1889), as to *Miers 1363*. *T. recurvata* var. *majuscula* Mez in Mart. Fl. Bras. iii. pt. 3, 611 (1894). *T. bandensis* var. *intermedia* Hassler in Ann. Cons. & Jard. Bot. Genève, xx. 333 (1919); Castellanos, Brom. & Cact. in Physis, x. 86, t. 2 (1930).

BOLIVIA: Santa Cruz: Cerro de Alto Mairana, alt. 2000 m., 1921, *Steinbach 6039* (FM). PARAGUAY: Gran Chaco, Santa Elisa, 23° 10′ S. lat., 1903, *Hassler 2778* (Bo, type of var. *intermedia;* G, BM). URUGUAY: Salto: 1924, *Schroeder* (Ost 17768 b, G); San José: near San José, *Arechavaleta 2612* (Mez!); Colonia: Carmelo, 1922, *Schroeder* (Ost 16442, G); Indefinite: *Tweedie* (K, type; phot. G); *Miers 1363* (BM). ARGENTINA: Formosa: Rio Pilcomayo, *Kerr 109* (K, phot. G); Formosa, *Jörgensen 2010* (G, US, Mo); *Jörgensen s. n.* (Ost 13780); *Jörgensen 1129* (Castellanos!); Chaco: Resistencia, 1924, *Castellanos 24/1246* (Castellanos!); Jujuy: Quinta, near Laguna de la Brea, 1901, *Fries 417* (S); Rio Chijra, 1924, *Schreiter 2605* (Castellanos!); Salta: Gran Chaco Salteño, Ipaguazo, 1902, *Calcagnini* (Castellanos!); Rio Juramento, 1922, *Castellanos* (Castellanos!); Orán, 1931, *Ragonese* (Castellanos!); Tucumán: dept. Trancas, Vipos, alt. 786 m., 1923, *Schreiter 1265* (Ost, G); Vipos, 1922, *Schreiter 27/2340* (Castellanos!); near Tucumán, 1926, *Schreiter 26/2375*; 1927, *27/2879* (Castellanos!); El Duraznito, near Tucumán, alt. 600 m., 1924, *Venturi 2801* (Ost, S, BA); dept. Trancas, Tapia, alt. 750 m., 1920, *Venturi 1119* (FM, S, Ost, BA); Chañar Pozo, 1919, *Venturi 1127* (Castellanos!); Catamarca: Quebrada de Totoral, Concepción, 1909, *Castillon 6601* (Castellanos!); El Valle, 1886, *Spegazzini 159* (Castellanos!); dept. El Alto, 1928, *Balcosna in hb. Venturi 7184* (Castellanos!); Santiago del Estero: La Parilla, near Gancedo, 1924, *Castellanos 24/1318* (G, BA); Sotelo, 1915, *De Carles 1130* (Castellanos!); La Rioja: General Roca, San Francisco, 1928, *Gomez 28/744* (Castellanos!); Córdoba: dept. San Javier, Yacanto, 1921, *Molfino* (Castellanos!); Santa Fe: Malabrigo, F. C. a Reconquista, 1906, *Schroeder* (Castellanos!); Entre Rios: Concordia, Duraznal, 1931, *Castellanos 31/978* (Castellanos!); Buenos Aires: Delta del Paraná, isla Forges, 1902, *Hicken 101* (Castellanos!); Delta del Paraná, Rio Barca Grande, 1931, *Cabrera 1634* (G, SP); Delta del Paraná, 1916, *Hauman 28/1131* (Castellanos!); San Isidro, 1906, *Hauman 1128* (Castellanos!).

Mez's citations of *T. bandensis* are so badly mixed geographically that it is not possible to use them without further checking, although I have little doubt of their taxonomic accuracy. The main trouble is his interpretation of the old term, "*Banda Oriental*," as Paraguay, when it should be Uruguay. In addition I can find no basis for his considering that the Tweedie material came from Brazil.

As already pointed out in Ostenia, Hassler's var. *intermedia* differs from Mez's description of the type of *T. bandensis* but not from the type.

23. **Tillandsia** (§ **Phytarrhiza**) **Mallemontii** Glaziou. Plant up to 25 cm. long: roots present: stem very slender, 1–2 dm. long, branching: leaves distichous, up to 12 cm. long, cinereous, densely pruinose-lepidote; sheaths narrowly ovate, up to 2 cm. long, membranaceous, glabrous within and below on the outside; blades mostly spreading or reflexed, irregularly curved, linear, long-acuminate, 1–1.5 mm. in diameter: scape terminal, erect to strongly curved, up to 13 cm. long, lepidote, almost filiform; scape-bracts like the floral bracts but sometimes long-laminate, 1 or 2 immediately below the inflorescence or rarely one somewhat remote: inflorescence always simple and distichous, narrowly lanceolate, complanate, 25 mm. long

and 4 mm. wide not counting the petals, densely 1–4-flowered; rhachis glabrous, compressed, slightly geniculate; floral bracts slightly more than twice as long as the internodes but not really imbricate because separated by the flowers at anthesis, ovate, acute, up to 9 mm. long, ecarinate, prominently nerved, thin, densely lepidote: flowers strictly erect, subsessile; sepals suboblong, acute, 12.5 mm. long, glabrous, nerved, equally short-connate; petals up to 17 mm. long, claw linear, blade suborbicular, obtuse, 6.5 mm. broad, spreading at anthesis, blue or violet; stamens deeply included, exceeding the pistil, anthers oblong, obtuse, 2 mm. long; ovary cylindric, abruptly contracted into the short thick style.—Terrestrial and epiphytic; Brazil.—Glaziou ex Mez in Mart. Fl. Bras. iii. pt. 3, 608, t. 114, fig. 1 (1894); Mez in DC. Mon. Phan. ix. 859 (1896); Silveira, Narrativas e Memorias, i. 277 (1924); Flor. Montium, ii. 6, t. 8 (1931). *T. linearis* Vell. sensu Bak. Journ. Bot. xxv. 234 (1887); Brom. 164 (1889), non Vell. (1825). *Phytarhiza uniflora* E. Morr. ex Bak. Brom. 164 (1889), in synon.

BRAZIL: RIO DE JANEIRO: Alt. Macahé, near Nova Friburgo, 1891, *Glaziou 18563* (US, K, phot. G); FEDERAL DISTRICT: near Tijucá, *Glaziou 14345* (B, TYPE; K); horto imperiali, São Christovão, Rio de Janeiro, 1892, *Lindman A 35* (S); same, 1897, *Ule 1313 in part* (MN Rio); SÃO PAULO: *St.-Hilaire Cat. C*^{2}, *1451* (P); PARANÁ: *Binot* (Mez!); Villa Velha, 1904, *Dusén 4107* (MN Rio); Jaguariahyva, alt. 740 m., 1910, *Dusén 10071* (S); Porto Amazonas, alt. 700 m., *Lange in hb. Dusén 9530* (S); SANTA CATHARINA: near Tubarão, *Ule 1313 in part* (Mez!); RIO GRANDE DO SUL: Cachoeira, on the road to Colonia S. Angelo, 1893, *Lindman A 1007* (S); Pelotas, 1923, *Parcus* (Ost 17082).

When the petals of *T. Mallemontii* are well expanded there is no danger of mistaking it for *T. recurvata*, but except for the petals there is no one character that holds. Within the range of *T. Mallemontii*, *T. recurvata* is usually much smaller. *T. Mallemontii* combines the characters of large size, long stem and all floral bracts shorter than the sepals. *T. recurvata* has the same characters but not all combined at once.

Mez gives *Phytarhiza uniflora* as a synonym of *Tillandsia recurvata*, presumably on the ground that *Tillandsia uniflora* was. However, there is no evidence that Morren intended *Phytarhiza uniflora* as a new combination and his plate in the Kew herbarium is unmistakably *T. Mallemontii*.

24. **Tillandsia** (§ **Diaphoranthema**) **loliacea** Mart. Plants up to 17 cm. long but usually much less: roots present: stem usually evident, simple or branched, rarely more than 4 cm. long: leaves densely polystichous, up to 4 cm. (Mez!) but usually 2–3 cm. long,

cinereous to fuscous, densely and coarsely pruinose-lepidote; sheaths ca. 3 mm. long, but slightly broader than the blade, glabrous, pale, subcoriaceous with broad hyaline margins, prominently nerved; blades erect to suberect or arching-secund, rigid, very narrowly triangular, long-acuminate but not filiform, 3–5 mm. wide at base: scape terminal, straight or curving, up to 10 cm. long, less than 1 mm. in diameter, lepidote; its bracts numerous, about equaling the internodes, elliptic, acute, chartaceous, prominently nerved, densely lepidote: inflorescence always simple and distichous, linear, up to 4 cm. long, very much like that of *Lolium* in its size and sinuous outline, up to 16-flowered (Hoehne!) but often with very few; rhachis strongly geniculate, flattened and excavated next the flowers, lepidote; floral bracts not at all imbricate, about one and a half times as long as the internodes, closely enfolding the flowers, ovate, acute, 8 mm. long, equaling or shorter than the sepals, thin, strongly nerved, densely lepidote: flowers erect and appressed to the rhachis, subsessile; sepals lanceolate, acute, up to 9 mm. long, glabrous, prominently nerved, equally short-connate; petals 10 mm. long, pale violet (Mez!) to yellow, claw sublinear, blade narrow, acute; stamens deeply included, exceeding the pistil, anthers 1.25 mm. long; ovary short-cylindric, abruptly contracted into the thick style; ovules long-caudate: capsule slenderly cylindric, short-beaked, up to 45 mm. long (Mez!).—Terrestrial and epiphytic; Brazil, Peru, Bolivia, Paraguay, Uruguay, Argentina.—Mart. ex R. & S. Syst. vii. 1204 (1830); Bak. Journ. Bot. xxv. 344 (1887); Brom. 189 (1889); Mez in Mart. Fl. Bras. iii. pt. 3, 611, t. 114, fig. 2 (1894); Mez in DC. Mon. Phan. ix. 862 (1896); O. Ktze. Rev. Gen. iii. 304 (1898); Mez, Plant. Hassl. ii. 259 in Bull. Herb. Boiss. ser. 2, iii. 1037 (1903); Chod. & Vischer, Vég. Par. in Bull. Soc. Bot. Genève, ser. 2, viii. 202–64, t. 76, 81–5 (1916); Hassler in Ann. Cons. & Jard. Bot. Genève, xx. 333 (1919); Hoehne in Comm. Linh. Telegr. Estrat. Matto-Grosso (Publ. 47), Annexo, v. Bot. pt. 9, 14, t. 164 (1919); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 504 (1933). *T. undulata* Bak. in Journ. Bot. xvi. 240 (1878); xxv. 213 (1887); Brom. 162 (1889). *T. quadriflora* Bak. Brom. 163 (1889), in part. *T. atrichoides* S. Moore in Trans. Linn. Soc. ser. 2, iv. 491 (1895).

BRAZIL: Ceará: Cariri, 1910, *Löfgren 496* (S, MN Rio); Bahia: Monte Santo, near Joazeiro, *Martius* (Mun, type; phot. G); Minas Geraes: *Glaziou 13241* (P); Conselheiro Matta-Rodeador, 1934, *Brade 13498* (JB Rio, G); São Paulo: Descalvado, 1932, *A. Gehrt in hb. S. P. 29795* (G, SP); Matto Grosso: between Corumbá and Ladário, 1892, *S. Moore 1046* (BM, type of *T. atrichoides;* phot. G); Diamantino, 1894, *Lindman b* (S); Corumbá, 1902, *Robert in hb. Sladen 791* (BM); 1911, *Hoehne 3556-9* (MN Rio). PERU:

Mathews (Mez!). BOLIVIA: Santa Cruz: Velasco, alt. 200 m., 1892, *Kuntze* (NY); Oriente, Charagua, alt. 800 m., 1934, *Cardenas 2681* (G); Indefinite: *Mandon 1176; Weddell 4175* (Mez!). PARAGUAY: mouth of the Rio Spane, near Villa Concepcion, 1875, *Balansa 619* (K, type of *T. undulata;* phot. G); Asuncion, 1874, *Balansa 619 a* (S); northern Paraguay, 1892, *Kuntze* (NY); El Chaco, Banks of the Rio Pilcomayo, 1893, *Lindman a* (S); Asuncion, Itapitapunta, 1893, *Lindman A 1611 a* (S); Paraguarí, 1893, *Lindman A 1611 b* (S); Cordillera de Altos, *Hassler 3861* (Mez!); Cerro Hu, Paraguary, *Hassler 2609* (Mez!); near Concepcion, *Hassler 7434* (Mez!); central Paraguay, *Rojas 1309* (Hassler!); *Chodat & Vischer 102, 102 bis* (Hassler!); San Bernardino, Ypecarai, 1915, *Osten 8106* (G, Ost, S); 1916, *Osten 8920, 8922 b* (Ost). ARGENTINA: Misiones: *Niederlein* (Mez!); Formosa: Guayculé, *Jörgensen 3396* (G, US, Mo, BA); Formosa, 1917, *Muello* (Castellanos!); Chaco: near Resistencia, *Niederlein* (Mez!); Jujuy: Quinta, near Laguna de la Brea, 1901, *Fries 207, 415* (S); Santa Clara, 1901, *Fries 497* (S); Moralitos, 1922, *Castellanos* (Castellanos!); Salta: Gran Chaco Salteño, Ipaguazo, 1902, *Calcagnini* (Castellanos!); Tabacal, 1928, *Burkart 28/707* (Castellanos!); between Embarcación and Yacuiba, 1923, *Hauman 1568* (Castellanos!); Corrientes: near Riachuelo, *Niederlein* (Mez!); Indefinite: *Hieronymus* (Mez!).

25. **Tillandsia** (§ **Diaphoranthema**) **erecta** Gill. Plant up to 11 cm. long: roots present: stem 3–6 cm. long, simple or few-branched: leaves densely polystichous, up to 5 cm. long, cinereous, densely and coarsely pruinose-lepidote; sheaths broadly ovate, ca. 5 mm. long, glabrous within and at the extreme base outside; blades erect to spreading, very narrowly triangular, involute-subulate, rigid, prominently nerved, angled toward apex, ca. 4 mm. broad at base: scape terminal, up to 45 mm. long, slender, strongly sulcate, glabrous, naked or with a single elliptic glabrous bract ca. 15 mm. long: inflorescence of a single flower with the rhachis prolonged behind it; floral bract triangular-ovate, acute, 8–10 mm. long, equaling or shorter than the sepals, glabrous, prominently 7–10-nerved: flower subsessile; sepals elliptic-lanceolate, acute, 10 mm. long, glabrous or scantly lepidote, prominently nerved, equally short-connate; petals narrowly elliptic, yellow in the dried material, punctate; stamens deeply included, exceeding the pistil: capsule slenderly cylindric, ca. 2 cm. long, abruptly short-beaked.—Epiphytic; Argentina.—Gill. ex Bak. in Journ. Bot. xvi. 239 (1878); xxv. 213 (1887); Brom. 162 (1889); Mez in DC. Mon. Phan. ix. 866 (1896); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 244 (1917). *T. rigida* Gill. ex Bak. in Journ. Bot. xvi. 239 (1878), in synonymy; Mez in DC. Mon. Phan. ix. 884 (1896). "Var. *T. rigida*" Gill. ex Bak. Brom. 162 (1889).—Pl. IV, fig. 2.

ARGENTINA: Mendoza: foot of the cordillera, near Mendoza, without date, *Gillies* (K, type; phot. G); same, 1822, *Gillies* (K, type of *T. rigida;* phot. G); Indefinite: *Castellanos* (G, BA).

26. **Tillandsia** (§ **Diaphoranthema**) **funebris** Castellanos.

Plant small, rarely over 10 cm. long including the inflorescence: stems several from a single point, densely massed, simple or few-branched, 2–5 cm. long: roots present: leaves densely distichous or polystichous, up to 5 cm. long; sheaths distinct, suborbicular to reniform, densely imbricate, making the stem appear stout, 5–8 mm. long, glabrous below, subcoriaceous, many-nerved with broad nerveless membranaceous margins; blades divergent to reflexed, more or less contorted, triangular-subulate, 2–3 mm. thick, strongly angled but not at all sulcate-striate, often distinctly keeled below, convolute above, acuminate, densely cinereous-lepidote with small nearly symmetrical subappressed to reflexed-pruinose scales: scape distinct, always terminal apparently, slender, erect, up to 5 cm. long, glabrous, strongly angled, naked for most of its length; scape-bracts oblong-lanceolate, acute, up to 17 mm. long but usually about 13 mm., subcoriaceous, many-nerved, even, 2 in number, usually a somewhat lepidote one near the base of the scape and a glabrous one just below the inflorescence: inflorescence 1–2-flowered, glabrous; floral bracts like the upper scape-bract but more ovate and progressively smaller, from slightly shorter to slightly longer than the sepals, even; rhachis like the scape and nearly as thick, swollen at the nodes: flowers subsessile, erect; sepals lanceolate, acute, even, many-nerved, 10 mm. long, equally connate for about 2 mm.; petals 13 mm. long, dark orange-brown when dry, coffee-colored when fresh (Venturi!), blade distinct, subrhombic, obtuse, spreading and often circinnate at anthesis; stamens deeply included, anthers basifixed, linear, acutish, less than 2 mm. long, filaments slightly shorter than the pistil; ovary ellipsoid, obtusely angled, contracted into the short thick style, stigma broadly capitate: capsule slenderly cylindric, 2 cm. long: seeds few.—Epiphytic; southeastern Bolivia and northwestern Argentina.—Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 502 (1933).

BOLIVIA: SANTA CRUZ: Oriente, Charagua to Izozog, alt. 800 m., 1934, *Cardenas 2688* (G). ARGENTINA: SALTA: La Candelaria, Unquillo, 1931, *Schreiter 6619* (Castellanos!); TUCUMAN: dept. Trancas, Vipos, alt. 786–850 m., 1922, *Venturi 1873* (G, US, S); *Schreiter 1689* (BA 27/2362, TYPE; G); 1923, *Schreiter 160 r* (Osten 17377).

This species is probably a close relative of *T. aizoides*, having the same trait of an isolated scape-bract just below the inflorescence, but its larger and spreading leaves distinguish it at first glance. In habit, *T. funebris* closely resembles *T. erecta.*

Castellanos records larger measurements for parts of the inflorescence than I have been able to find.

T. funebris is one of the species which appear transitional between *Phytarrhiza* and *Diaphoranthema.*

27. **Tillandsia** (§ **Diaphoranthema**) **tricholepis** Bak. Plant moss-like: roots present: stems many from a single point, densely massed, at first bearing flowers when short and simple but later elongate and much branched, up to 22 cm. long including the longest branch, but usually much less: leaves densely polystichous, up to 15 mm. long but averaging about 10 mm.; sheaths distinct, broadly ovate, glabrous and covered by the one below except at the extreme apex, membranaceous, scarious with 4 to 5 central nerves and broad nerveless margins; blades appressed to somewhat divergent, narrowly triangular, subulate-acuminate, involute, densely ferruginous- or cinereous-furfuraceous with lacerate asymmetric scales produced below into a spreading lobe so that under a lens the leaves appear reflexed-tomentose: scapes at first terminal, soon becoming pseudo-axillary by the elongation of the stem, slender, straight or somewhat flexuous, 1–4 cm. long, 0.3–0.5 mm. thick, sulcate, soon glabrous; scape-bracts several, evenly distributed, nearly or quite as long as the internodes, closely enfolding and concealing most of the scape, lanceolate, acute, membranaceous, sulcate, lepidote, 5–8 mm. long: inflorescence always of a single spike, 1–5-flowered, sometimes with a sterile floret at apex, narrowly lanceolate, up to 17 mm. long; rhachis slender, nearly straight, strongly angled, glabrous; floral bracts like the scape-bracts but broadly ovate, enfolding the rhachis for about half their length, slightly but consistently shorter than the sepals: flowers erect, subsessile but appearing stipitate because of the narrowing of the calyx-tube, up to 9 mm. long; sepals lanceolate, acute, equally connate at base for 1.5 mm., 6.5 mm. long, glabrous or with a very few scales, membranaceous, strongly nerved; petals pale yellow, punctate, linear, blade indistinct, obtuse, spreading at anthesis; stamens deeply included, less than half as long as the petals, exceeding the style, anthers linear, acutish, basifixed; ovary prismatic with a projecting ring just below the apex, style short but slender, stigmas just reaching the base of the anthers: capsule narrowly cylindric, abruptly contracted into a short beak, up to 2 cm. long, valves separating nearly to the base, remaining straight; seed narrowly fusiform, brown, up to 3 mm. long, with a short white beak at apex and at base a white coma up to 14 mm. long.—Epiphytic; eastern Brazil, Bolivia, Paraguay, and northern Argentina.—Bak. in Journ. Bot. xvi. 237 (1878); xxv. 213 (1887); Brom. 160 (1889); O. Ktze. Rev. Gen. iii. 304 (1898); Hassler in Ann. Cons. & Jard. Bot. Genève, xx. 334 (1919);

Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 507 (1933). *T. tricholepis* var. *argentea* Hassler in Ann. Cons. & Jard. Bot. Genève, xx. 334 (1919). *T. bryoides* Griseb. (in part) Symb. Arg. in Goett. Abh. xxiv. 334 (1879); Bak. Brom. 160 (1889); Morong & Britton, Enum. Pl. Parag. in Contrib. Herb. Columbia Coll. xxxv. in Ann. N. Y. Acad. Sci. vii. 236 (1892). *T. polytrichoides* E. Morr. in Belg. Hort. xxx. 240 (1880); Mez in Mart. Fl. Bras. iii. pt. 3, 612, t. 114, fig. 3 (1894); Mez in DC. Mon. Phan. ix. 863 (1896); Mez, Pl. Hassl. ii. 259, in Bull. Herb. Boiss. ser. 2, iii. 1037 (1903); Hassler, Fl. Pilcom. in Trab. Mus. Farmac. B. A. xxi. 41 (1909); Chod. & Vischer, Vég. Par. in Bull. Soc. Bot. Genève, ser. 2, viii. 210, 221, 232, 234, 260, t. 93–5 (1916); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 246 (1917); Herzog in Engl. & Drude, Veg. d. Erde, xv. 96–7 (1923); Lillo in Bol. Univ. Nac. Tucumán, i. no. 6, 5 (1925); Silveira, Narrativas e Memorias, i. 282 (1924); Flor. Montium, ii. 4, 5, 12, 13, t. 3 (1931); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930).

BRAZIL: Ceará: *F. Allemão CLXXI* (MN Rio); *Allemão & Cysneiros 1525; 1526 in part* (MN Rio); Minas Geraes: Conselheiro Matta-Rodeador, 1934, *Brade 13497* (JB Rio, G); Rio de Janeiro: on ironwork over Rio Parahyba, Barra do Pirahy, *Silveira* (Silveira!); Federal District: São Christovão, Rio de Janeiro, *Glaziou 3124; Schwacke 5458* (Mez!); 1892, *Lindman A 37* (S); 1929, *Brade 2168* (G); Indefinite: *Glaziou 66* (type of *T. polytrichoides*). BOLIVIA: El Beni: Trinidad, alt. 250 m., 1926, *Werdermann 2396* (S); La Paz: Poquerani, San Pedro, near Sorata, alt. 2500–2650 m., 1859, *Mandon 1179 in part* (K, type; BM, S, G, NY); Apolo, 1902, *R. S. Williams 1486* (NY, US, BM); prov. Inquisivi, Cañamina, alt. 1700 m., 1921, *O. E. White 272* (NY); Santa Cruz: Santa Cruz de la Sierra, alt. 1600 m., 1892, *O. Kuntze* (NY); "monte," Camatindi near Cumbarute and Woyuywe, Rio Parapiti, ca. 20° 25′ S. lat., 1910, *Herzog 1195* (S); Chaco, Agua Caliente near Charagua, alt. 800 m., 1934, *Cardenas 2611* (G, FM); Indefinite: 1861–3, *Pearce* (BM); *Weddell 3655* (P). PARAGUAY: Asuncion, 1874, *Balansa 617* (S, G, US); central Paraguay, between Villa Rica and Escoba, 1888–90, *Morong 492* (NY, G, US, Mo, BM); central Paraguay, *Balansa 617 a; Hassler 2610; Chodat & Vischer 93; 103* (Hassler!); upper Rio Apa, *Hassler 8517* (Hassler!, type of var. *argentea*); Pilcomayo River, Gran Chaco, *Morong 1086* (NY, BM); *Rojas 686* (Hassler!, as var. *argentea*); Cerros de Acahy, 1919, *Hassler 152* (Ost); northern Paraguay, 1892, *O. Kuntze* (NY); Asuncion, Itapitapunta, 1893, *Lindman 1611* (S); Colonia Elisa near San Antonio, 1893, *Lindman A 1781* (S, G); El Chaco, Paso Manduvi, Rio Pilcomayo, 1893, *Lindman A 1897 1/2* (S, G); El Chaco, Obraje Gill, Rio Pilcomayo, 1893, *Lindman A 1905 1/2* (S, G); Cerro de Acahy, 1919, *Rojas 152* (Ost); Ypacarai, San Bernardino, 1915, *Osten 8105* (Ost); indefinite, *Weddell 3222* (P). ARGENTINA: Formosa: Formosa, 1917, *Jörgensen* (S); 1919, *2800* (G, Mo); near Laishi, 1918, with *Jörgensen 2576* (Ost); Jujuy: Quinta near Laguna de la Brea, 1901, *Fries 416* (S); dept. Ledesma, Sierra de Calilagua, alt. 700 m., 1927, *Venturi 7291* (US); San Pedro, 1893, *Spegazzini 163* (Castellanos!); Salta: Salta, 1901, *Fries 14* (S); dept. Orán, Obra Grande, alt. 750 m., 1927, *Venturi 5620* (US); Orán, 1931, *Ragonese* (Castellanos!); Termas de Rosario de la Frontera, 1931, *Herborn* (Castellanos!); Orán, Pichanal, 1913, *Rodriguez 1119* (G, BA);

dept. Candelaria, Sierra de la Candelaria, alt. 1100 m., 1924, *Venturi 4080* (US); Tartagal, 1924, *Schreiter 3508* (Castellanos!); 1930, *Parodi 9232* (G); TUCUMAN: La Cruz, 1872, *Lorentz & Hieronymus 60* (NY); Tafi viejo, *Tatter in hb. Kurtz 4146* (Mez!); Lules, 1916, *Sanzin 1160* (Ost); Alpachiri, 1916, *Jörgensen* (Ost 11666); dept. Trancas, Vipos, alt. 850 m., 1922, *Venturi 1977* (G, US); dept. Capital, El Duraznito, alt. 600 m., 1924, *Venturi 2799* (G); indefinite, 1918, *Schreiter 800* (Ost, S); SAN JUAN: San Juan, 1931, *Correa* (Castellanos!); CÓRDOBA: 1877, *Hieronymus* (BM); Estancia Germania, near Córdoba, 1874, *Lorentz 128 in part* (BM, Mun); near Córdoba, 1876, *Hieronymus 482* (FM); Chacra de La Merced, 1881, *Hieronymus* (NY); SANTA FE: Colonia Margarita, 1905, *Wolfhügel* (Castellanos!).

The name of *T. tricholepis* for this species has clear priority over the others. Mez chose the later *T. polytrichoides*, so far as can be inferred without any explanatory note, because the type of *T. tricholepis* came from a mixed number. Yet Baker clearly distinguished *T. tricholepis* from *T. bryoides*, the other species under *Mandon 1179*, when he said: "Peduncle . . . 1–2-flowered, . . . with several . . . bracts." These few words eliminate *T. bryoides* completely, since it never has more than one flower and its peduncle or scape if present is always naked. Mez's distinction in the key to his monograph is really less complete when it divides between inflorescence 1-flowered and more than 1-flowered, because in *T. tricholepis* the inflorescence on the same plant may be both 1-flowered and up to 5-flowered as in *Morong 492* (G). The real point between the two is the presence or absence of scape-bracts.

Hassler's variety *argentea* does not appear tenable to me, since the color of the leaf-scales varies considerably on a single plant and appears to be largely a matter of age and treatment in collecting.

28. **Tillandsia** (§ **Diaphoranthema**) **bryoides** Griseb. emend. L. B. Smith. Plant small and with a habit like that of *Lycopodium Selago:* roots present: stems many from a single point, densely massed, simple or sparingly branched, rarely more than 5 cm. long including the longest branch: leaves densely polystichous, 4–9 mm. long but averaging about 6 mm.; sheaths distinct, broadly ovate or triangular to suborbicular, usually as long as the blade, glabrous below, membranaceous, scarious, with 3 central nerves which often touch and broad nerveless margins; blades erect, strict, making the stem appear terete, subtriangular, acute, concave above, convex below, becoming obtusely carinate toward base, up to 2 mm. broad, densely cinereous-lepidote, the scales varying from suborbicular to strongly asymmetric with an elliptic or triangular basal lobe, denticulate, spreading at base so that under a lens the leaves appear reflexed-tomentose: scape often lacking so that the inflorescence is sunk among the terminal leaves, when present evidently elongating only after anthesis, erect,

slender, glabrous, sulcate, naked or with a single lanceolate bract enfolding its extreme base, up to 3 cm. long: inflorescence usually terminal but sometimes becoming pseudoaxillary by the elongation of the stem, always composed of a single flower; floral bract up to 7 mm. long, triangular-ovate, hyaline with a single median excurrent nerve, glabrous or with a few scales toward apex: flower subsessile; sepals linear-elliptic, 5–9 mm. long, obtuse or acute, hyaline, 3-nerved, slightly exceeding the floral bract, equally short-connate for about 1 mm. at base; petals linear with little distinction between claw and blade, erect or nearly so at anthesis, not twisted, fleshy, orange-brown when dry, sulphur-yellow when fresh (Schreiter! Castellanos!); stamens deeply included, anthers linear, filaments about equaling the pistil; ovary subprismatic, stout, abruptly contracted into the short but slender style, stigma capitate: capsule slenderly cylindric, abruptly contracted into a short beak, up to 17 mm. long; seeds few.—Epiphytic and saxicolous; Peru, Bolivia, Argentina.—Griseb. ex Bak. in Journ. Bot. xvi. 236 (1878); xxv. 213 (1887); Griseb. Symb. Argent. in Goett. Abh. xxiv. 334 (1879); Lor. & Niederl. in Roca, Exped. Rio Negro, ii. 283 (1881); Wittm. in Engl. & Prantl, Nat. Pflanzenf. ii. Abt. 4, 56 (1888); Bak. Brom. 160 (1889); O. Ktze. Rev. Gen. iii. 303 (1898). *T. coarctata* Gillies ex Bak. in Journ. Bot. xvi. 236 (1878) in synonymy, not Willd. (1830); Ball (authority wrongly given as "W"), in Journ. Linn. Soc. xxi. 234 (1884); Mez in DC. Mon. Phan. ix. 865 (1896); Macloskie, Rep. Princeton Univ. Exped. Patagonia, viii. 293 (1904); Hicken, Notas Bot. 13 (1908); Hauman in An. Mus. Nac. Hist. Nat. B. A. xxiv. 376 (1913); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 243 (1917); Herzog in Engl. & Drude, Veg. d. Erde, xv. 97 (1923); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 499 (1933). *T. coarctata* var. *pedicellata* Mez in DC. Mon. Phan. ix. 865 (1896); Macloskie, Rep. Princeton Univ. Exped. Patagonia, viii. 294 (1904); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 499 (1933).—Pl. IV, figs. 5–7.

PERU: *Gay 1574* (P). BOLIVIA: La Paz: prov. Larecaja, near Sorata, alt. 2500–2650 m., 1858–9, *Mandon 1179 in part* (K, BM); indefinite, alt, over 4000 m., *Pentland 29* (P); Huancana, alt. 2800 m., 1906, *Buchtien 806* (US, NY); Cotaña, near Illimani, alt. 2450 m., 1911, *Buchtien 4144* (G); Potosi: Rio Blanco, 1932, *Cardenas 318* (US); Cochabamba: Parotani, alt. 2400 m., 1892, *Kuntze* (NY); Santa Cruz: "monte," Cumbarute and Woyuywe, Rio Parapiti, ca. 20° 25′ S. lat., 1910, *Herzog* (Herzog!); Oriente, Charagua to Izozog, alt. 800 m., 1934, *Cardenas 2690* (G); Chuquisaca: Camataqui, alt. 1800 m., 1932, *Cardenas 213* (G); Indefinite: *Miers 7592–7592x* (BM).

ARGENTINA: Jujuy: termas de Reyes, 1928, *Burkart 27/708* (Castellanos!); Volcán, 1927, *Castillon 6571* (Castellanos!); 1922, *Castellanos* (Castellanos!); Salta: Metán, 1930, *Castellanos 30/3026* (Castellanos!); Cafayate, 1919, *Hauman 1133* (Castellanos!); indefinite, *Weber* (Mez!); Tucumán: dept. Trancas, Vipos, 1921, *Schreiter 27/2360* (G, BA); same, alt. 786 m., 1922, *Schreiter 2029* (Ost); same, alt. 850 m., 1922, *Venturi 1978* (G, US, Ost, BA); Catamarca: 1899, *Spegazzini 199* (Castellanos!); 1904, *Baldi* (Castellanos!); Santiago del Estero: near Santiago, 1906, *Spegazzini 198* (Castellanos!); La Rioja: Sierra de Famatina, Guanchín, 1928, *Castellanos 28/106* (Castellanos!); Córdoba: Sierra Achala, *Hieronymus 795 in part* (BM); Sierra Chica, "El Zapato," near Capilla del Monte, alt. ca. 1000 m., 1917, *Osten 10543* (Ost); 1918; *Osten 13469* (Ost, S); *13470* (Ost); Sierra Chica, Rio Pintos, alt. ca. 1000 m., 1918, *Osten 13495* (Ost, S); between Rio Pintos and Characate, *Osten 13494* (Ost); Sierra Chica, Los Paredones, near Capilla del Monte, alt. ca. 1000 m., 1918, *Osten 13468* (Ost); Valle de los Reartes, 1920, *Castellanos* (Ost 15281); 1925, *Castellanos 25/1748* (G, BA); Sierra Grande, 1920, *Castellanos* (Ost 15282); dept. San Javier, Yacanto, 1920, *Hauman 1135* (Castellanos!); Achala cuesta del Mogote, 1922, *Castellanos 1589* (Castellanos!); indefinite, *Lossen 189* (G, Mo); *Miers 1084* (BM); *Lorentz 128 in part* (type); 1876, *Hieronymus 133* (US); San Luis: Quebrada del Salado, 1882, *Galander* (US); Quines, quebrada del Zapallar, 1925, *Castellanos 25/619* (Castellanos!); Concarán, 1925, *Castellanos 25/2626* (Castellanos!); Cerro Varela, 1925, *Castellanos 25/2777* (Castellanos!); Santa Rosa del Gigante, 1926, *Castellanos 26/2047* (Castellanos!); Los Gigantes, 1926, *Castellanos 26/2044* (Castellanos!); San Francisco, quebrada de Ramos, 1925, *Castellanos 25/617* (Castellanos!); Mendoza: foot of the Cordillera near Mendoza, 1825, *Gillies* (Cam, K, type of *T. coarctata;* phot. G); Potrerillos, alt. 1400 m., 1907, *Osten 5107* (Ost); Precord. San Ignacio, alt. 1300 m., 1915, *Sanzin 566* (Ost); Cacheuta, 1916, *Ruiz 116* (G, BA); San Rafael, Cañada Seca, 1921, *Ruiz 901* (G, BA); Buenos Aires: Rio Negro Inferior, 1912, *Hauman 1134* (Castellanos!); Sierra Ventana, 1881, *Lorentz 751* (Ost); *Lorentz* (US); *Hicken* (Castellanos!); La Pampa: Sierra Lihuel Calel, 1927, *Castellanos 27/266* (Castellanos!); Chubut: Camarones, 1912, *Aurelius 23* (S, phot. G); Indefinite: northern Argentina, *Hieronymus 351; 883; Hieronymus & Niederlein 852; Lorentz 351; Niederlein 26 in part* (Mez!); valley of the Rio Colorado, near Fuerte Pinzen, 1879, *Lorentz & Niederlein* (L. & N.! Mez!); valley of the Rio Negro, *Claraz 207* (Ball!); Sierras Pampeanas, 1881, *Lorentz 47* (NY).

Tillandsia bryoides was described from a mixed sheet and the original description unfortunately contained both elements. One element had already been described as *T. tricholepis*, so that the description is amended here to fit the previously undescribed second element. The only definite correction is that the spikes never have more than a single flower instead of: "Flowers 1–3." The name *T. coarctata* is invalid for this species by both the priority and homonym rules.

Osten 5107 has both flowers and fruit, and the flowers are all sessile while the fruits are all elevated on a definite scape. This evidence would indicate that the scape elongates only after anthesis. If individuals were consistent in this process Mez's *T. coarctata* var. *pedicellata* would be a valid distinction, but capsules both with and without a scape may be found on the same plant as in *Aurelius 23*.

Aurelius 23 is further noteworthy in that it establishes a new southern limit (ca. 45° S. lat.) for the entire *Bromeliaceae*.

29. **Tillandsia** (§ **Diaphoranthema**) **aizoides** Mez. Plant small and with a habit closely resembling that of *T. bryoides* but coarser and less compact: roots present: stems many from a single point, densely massed, simple or sparingly branched, up to 4 cm. long: leaves densely polystichous, usually about 10 mm. long, rarely up to 20 mm. (Mez!); sheaths distinct, broadly ovate, scarious, with 4–many nerves and broad nerveless margins; blades erect but somewhat divergent and not strict as in *T. bryoides*, sometimes slightly secund, angular-subulate, mucronate-acute, stout, 2 mm. thick, convex below, channeled above, densely cinereous-lepidote with reflexed-spreading scales: scape usually terminal, from very short to 2 cm. long, glabrous, angled, naked except for 1 or 2 bracts immediately below the flower or with a single bract midway; scape-bracts elliptic, acute, glabrous, often carinate (Mez!), sulcate with several strong nerves: inflorescence always composed of a single flower; floral bract elliptic, obtuse or apiculate, membranaceous, at least 3-nerved, shorter than the sepals: sepals elliptic, obtuse or acute, ca. 8 mm. long, glabrous, scarious, 5–7-nerved, connate anteriorly for 2 mm., posteriorly for 2.5 mm.; petals linear with little distinction between claw and blade, brownish when dry, probably yellow when fresh, but slightly exceeding the sepals; stamens deeply included, anthers linear; pistil not known: capsule slenderly cylindric, up to 2 cm. long, abruptly contracted into a short beak; seeds few.—Epiphytic and saxicolous; northwestern Argentina.—Mez in DC. Mon. Phan. ix. 866 (1896); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 242 (1917); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 498 (1933).—Pl. IV, figs. 8–9.

ARGENTINA: TUCUMÁN: near Tucumán, 1926, *Schreiter 26/2374* (Castellanos!); LA RIOJA: valley of Famatina, 1879, *Hieronymus & Niederlein 850* (B, TYPE; phot. G); Nonogasta, 1927, *Castellanos 27/1908* (Castellanos!); General Roca, San Francisco, 1928, *Gomez 28/743* (Castellanos!); CÓRDOBA: Chacrarita de los Padres, Quebrada de la Tala, *Lorentz & Hieronymus* (Mez!); Sierra Chica, "El Zapato," near Capilla del Monte, alt. ca. 1000 m., 1918, *Osten 13471* (Ost); dept. San Javier, Yacanto, 1920, *Hauman 1123* (Castellanos!); near Villa Dolores, 1920, *Castellanos 1577* (Castellanos!); Achala, 1920, *Castellanos* (Castellanos!); indefinite, *Lossen 253* (G, FM, Mo); SAN LUIS: San Francisco, quebrada de Ramo, 1925, *Castellanos 25/623* (Castellanos!); Luján, quebrada de las Higueras, 1925, *Castellanos 25/622* (Castellanos!); Cerro Varela, 1925, *Castellanos 25/2790* (Castellanos!); Nogolí, 1925, *Castellanos 25/630* (Castellanos!); Santa Rosa del Gigante, 1926, *Castellanos 26/2046* (Castellanos!).

As Mez has already pointed out this species is in many ways intermediate between *T. bryoides* and *T. rectangula* and possibly may be a hybrid between the two. Certainly it appears to be much less frequent than either of its supposed parents and its range appears to be contained within theirs, but as yet there is no direct evidence to support the conclusion.

Mez cites the floral bract as being 7-nerved while I can find but 3. This may possibly be explained from the fact that the bract is so transparent that the nerves of the sepals underneath show through and from many angles of view appear to belong to the bract itself.

30. **Tillandsia** (§ **Diaphoranthema**) **angulosa** Mez. Plant pulvinate: stem less than 25 mm. long: roots present: leaves distichous or polystichous, up to 15 mm. long, densely and coarsely appressed-cinereous-lepidote; sheaths suborbicular, thin, many-nerved, glabrous only at extreme base; blades spreading to recurved, triangular, stout, angled, mucronate: scape very short and hidden by the leaves but bearing a single ovate acute prominently nerved densely lepidote bract: inflorescence always 1-flowered; floral bract like the scape-bract, slightly shorter than the sepals, at least 5-nerved: sepals elliptic, acute, 10 mm. long, prominently nerved, thin, often scantly lepidote, subfree: capsule slenderly subcylindric, abruptly short-beaked, 2 cm. long.—Epiphytic; northwestern Argentina.—Mez in DC. Mon. Phan. ix. 868 (1896); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 242 (1917).—Pl. IV, fig. 16.

ARGENTINA: LA RIOJA: Valle de Famatina, 1879, *Hieronymus & Niederlein 851* (B, TYPE; phot. G).

Mez considered that this species might be a hybrid of *T. retorta* and *T. bryoides*, and it seems very likely not only because of the way it combines the characters of the two but also in its lack of constancy in such traits as the arrangement of the leaves.

31. **Tillandsia** (§ **Diaphoranthema**) **rectangula** Bak. Plant small: stems many from a single point, forming a dense globose mass, up to 5 or rarely 7 cm. long, much branched: roots present: leaves densely distichous but often appearing polystichous due to the torsion and crowding of the stems, rarely over 2 cm. long; sheaths distinct, suborbicular, ca. 6 mm. long, glabrous except for the extreme apex, densely imbricate making the stem appear stout, scarious, several-nerved with broad nerveless margins; blades spreading or recurved, more or less contorted, triangular-subulate, 2 mm. thick, strongly angled, often distinctly keeled below, convolute above, acuminate, densely cinereous-lepidote with small nearly symmetrical subappressed

to reflexed-pruinose scales: scape distinct or almost none, slender, erect or ascending, up to 4 cm. long (Mez!) but usually not over 2 cm., apparently always terminal, glabrous, strongly angled, naked for most of its length or sometimes bearing an involute-clasping bract midway; scape-bracts lanceolate, acute or obtuse, several-nerved, even, subcoriaceous, glabrous or occasionally pale-appressed-lepidote, usually 2 in number, one at the extreme base of the scape and mostly hidden by the leaves, the other just below the inflorescence: inflorescence always of a single flower; floral bract like the upper scape-bract but smaller, much shorter than the sepals: flower subsessile, sepals elliptic-lanceolate, up to 10 mm. long, acute or obtuse, chartaceous, even, several-nerved, glabrous or scantly pale-lepidote, equally connate for about 2 mm. or the posterior suture barely longer than the 2 anterior ones; petals yellow (Osten!), 4.5 mm. longer than the sepals, blade subrhombic, obtuse, spreading at anthesis; stamens included, anthers basifixed, linear, obtuse, little more than 1 mm. long, filaments distinctly longer than the pistil; ovary subprismatic, tapering into the thick style, stigma capitate: capsule slenderly cylindric, up to 20 mm. long, abruptly contracted into a short beak.—Epiphytic and saxicolous; northern Argentina.—Bak. Journ. Bot. xvi. 238 (1878); xxv. 213 (1887); Hieron. Ic. & Descr. Argent. in Act. Acad. Cien. Cordoba, ii. 17 (1885); Bak. Brom. 160 (1889); Mez in DC. Mon. Phan. ix. 867 (1896); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 247 (1917); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 506 (1933). *T. propinqua* Gay var. *rectangula* Griseb. Symb. Argent. in Goett. Abh. xxiv. 335 (1879).—Pl. IV, fig. 19.

ARGENTINA: Salta: Orán, 1906, *Spegazzini* (Castellanos!); Catamarca: near Recreo, *Tatter in herb. Kurtz 4333* (Mez!); Córdoba: near Córdoba, *Lorentz 127 in part* (K, type; phot. G); *126 in part* (BM); *Hieronymus 483* (FM); Sierra Chica, "El Zapato," near Capilla del Monte, alt. ca. 1000 m., 1918, *Osten 13472* (Ost); same, "Los Paredones," *Osten 13473* (Ost); same, 1923, *Osten 17764* (Ost); same, 1922, *Castellanos 1579* (G); dept. San Alberto, Yacanto, 1924, *Castellanos 1564* (G); near Merced, 1881, *Hieronymus* (US); indefinite, *Lossen 190* (G, FM, Mo, Mun); San Luis: Bajo de Velis, 1895, *Kurtz 8472* (Castellanos!); San Francisco, Quebrada de Ramo, 1925, *Castellanos* (BA 25/624, G).

32. **Tillandsia** (§ **Diaphoranthema**) **Castellani** L. B. Smith. Plant up to 15 cm. high when in flower: stems simple or few-branched, many from a single point: roots present: leaves densely distichous, up to 45 mm. long; sheaths broadly ovate, strongly nerved, densely lepidote with a ciliate margin of elongate scales; blades spreading or reflexed, sublinear, terete, 2–3 mm. in diameter, pungent, densely

pruinose-lepidote with cinereous scales: scape evident, terminal or pseudo-axillary, naked, glabrous, slender: inflorescence 1–2-flowered; floral bracts ovate, broadly acute, glabrous, strongly nerved, distinctly shorter than the sepals: flowers subsessile; sepals equally subfree, lanceolate, acute or obtuse, up to 9 mm. long, glabrous, strongly nerved; petals, stamens and pistil unknown: capsule slenderly cylindric, 15–25 mm. long.—Saxicolous; northern Argentina.—L. B. Smith in Contrib. Gray Herb. civ. 80, t. 3, figs. 17–19 (1934).

ARGENTINA: CÓRDOBA: Capilla del Monte, Los Paredones, 1922, *Castellanos 1576* (G, TYPE); same, alt. ca. 1000 m., 1918, *Osten 13474* (Ost); Cuesta de Atlantina, 1921, *Castellanos* (G); SAN LUIS: Quebrada de Ramo in San Francisco, 1925, *Castellanos in hb. BA 25/618* (G).

33. **Tillandsia** (§ **Diaphoranthema**) **Gilliesii** Bak. Plant over 2 dm. long when in flower: stems many from a single point, forming a dense subglobose mass, up to 8 cm. long, simple or few-branched: roots present: leaves very densely distichous, 2–8 cm. long, densely subappressed-lepidote with cinereous to ferrugineous subsymmetrical scales; sheaths broadly oblong, many-nerved with no distinct margin, merging imperceptibly with the blade, lepidote except for the extreme base, densely imbricate making the stem appear 5–7 mm. thick, not overlapping behind the stem except at the extreme base; blades arching-recurved, often somewhat contorted, narrowly triangular, much compressed laterally, acuminate, with a very narrow triangular channel on the upper side: scape distinct or almost lacking, terminal or pseudoaxillary, up to 13 cm. long, appressed-lepidote, naked or bearing a single lanceolate involute bract: inflorescence 1–3-flowered, up to 38 mm. long, densely cinereous-lepidote; rhachis flexuous; floral bracts erect, lance-ovate, acute, up to 20 mm. long, equaling or exceeding the sepals or the uppermost sometimes slightly shorter, not more than twice as long as the internodes, not at all keeled, many-nerved, thin: flowers subsessile; sepals oblong-lanceolate, acute or obtuse, up to 16 mm. long, thin, many-nerved, lepidote, equally subfree; petals narrow; stamens deeply included, exceeding the pistil; ovary subglobose, slightly longer than the style: capsule slenderly cylindric, 25 mm. long, abruptly short-beaked.—Epiphytic; southern Peru and Bolivia, northern Argentina.—Bak. in Journ. Bot. xvi. 240 (1878); xxv. 213 (1887); Brom. 162 (1889); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 503 (1933). *T. compressa* Gillies ex Bak. in Journ. Bot. xvi. 240 (1878), in synon, non Bertero. *T. andicola* Gill. sensu Wittm. in Reiss & Steubel, Todtenfeld v. Ancon, t. 106, fig. 15 (non Gill.)—Pl. IV, figs. 10–12.

PERU: Arequipa: below Tingo, 1914, *Mr. & Mrs. J. N. Rose 19014* (US, NY); Arequipa, alt. 2500 m., 1926, *G. H. H. Tate 1196* (NY). BOLIVIA: Chuquisaca: prov. Cinti, Puca Khasa, near Tacaquira, 1934, *Hammarlund 313* (S); Camataqui, alt. 1800 m., 1932, *Cardenas 214* (G). ARGENTINA: Salta: Molinos, 1897, *Spegazzini 203* (Castellanos!); Tucuman: Valle de Santa Maria, Quebrada de Las Arcas, 1920, *Schreiter 1365* (Castellanos!); between Amaicha and Tiopunco, 1931, *Schreiter 7340* (Castellanos!); Catamarca: Quebrada de San Buenaventura, 1930, *Castellanos in hb. BA 30/409* (Castellanos!); La Rioja: Sierra Velazco, Los Colorados, 1879, *Hieronymus & Niederlein 508* (Castellanos!); Nonogasta, 1927, *Castellanos in hb. BA 27/1905* (G); San Juan: Sierra Pie de Palo, 1896, *Spegazzini 204* (Castellanos!); Mendoza: foot of the cordillera near Mendoza, 1825, *Gillies* (K, type; G, Cam); Precordillera, 1906, *Carette 1126* (Castellanos!); near Mendoza, 1914, *Sanzin 1125* (Castellanos!); Pilar, 1916, *Ruiz 324* (Castellanos!); Buenos Aires: Sierra Ventana, 1881, *Lorentz* (Ost, US); La Pampa: Naicó, 1927, *Castellanos in hb. BA 27/2880* (G).

Castellanos has reërected this species, which Mez reduced to the synonymy of *T. myosura*. As he did not publish his reasons in treating *T. Gilliesii*, I am taking the liberty of so doing here and illustrating from some excellent living material he sent.

T. Gilliesii has leaves that are much compressed laterally and leaf-sheaths that show no distinction from the blades except their position, while *T. myosura* has leaves that are practically terete and leaf-sheaths that are noticeably broader than the blades. Also the sheaths in *T. Gilliesii* have margins barely overlapping, while in *T. myosura* they are strongly so (see Pl. IV, figs. 11 & 14).

The type sheet of *T. Gilliesii* shows the whole range of variation from the longest scape recorded to practically none.

34. **Tillandsiia (§ Diaphoranthema) myosura** Griseb. Plant large for the section *Diaphoranthema*, flowering specimens occasionally 3 dm. or more high: stems many from a single point, forming a dense subglobose mass, up to 10 cm. long but usually only about 6 cm., simple or few-branched: roots present: leaves densely distichous, 5–17 cm. long; sheaths distinct, suborbicular to reniform, 10–15 mm. long, normally with the upper half densely lepidote like the blade but sometimes wholly glabrous, even in the glabrous phase with a fringe of narrow marginal scales, densely imbricate making the stem appear 5–8 mm. thick, their margins overlapping behind the stem for most of their length; blades strongly recurved and more or less contorted, triangular-subulate, 3–5 mm. in diameter, evenly rounded when fresh with a channel along most of the upper side, becoming strongly sulcate when dry due to the shrinkage of tissue between the nerves, acuminate, densely cinereous-lepidote with small basally produced subappressed to reflexed-pruinose scales: scape always distinct, erect, terminal, up to 20 cm. long, lepidote or glabrous, naked or with a

single lanceolate involute lepidote bract well removed from the inflorescence: inflorescence linear, up to 8 cm. long, laxly 1–8-flowered, densely cinereous-lepidote; rhachis slender, flexuous in the few-flowered specimens, but usually geniculate in the larger ones; floral bracts remote, rarely more than twice as long as the internodes and often much less, particularly in the many-flowered specimens, closely enfolding the calyx, not concealing the rhachis except by their extreme base, broadly ovate, acuminate, up to 21 mm. long, the lower ones equaling or exceeding the sepals, the upper ones often distinctly shorter, chartaceous, prominently many-nerved: flowers erect, closely appressed to the rhachis, subsessile; sepals oblong-lanceolate, acute or obtuse, 9–15 mm. long, thin, many-nerved, usually more or less lepidote, equally subfree; petals linear, up to 20 mm. long, yellowish white; stamens deeply included, exceeding the pistil; style short-cylindric, about as long as the ovary: capsule cylindric, abruptly short-beaked, up to 35 mm. long.—Epiphytic; southern Bolivia, Uruguay and northern Argentina.—Griseb. ex Bak. in Journ. Bot. xvi. 240 (1878); xxv. 213 (1887); Griseb. Symb. Argent. in Goett. Abh. xxiv. 333 (1879); Wittm. in Engl. & Prantl, Nat. Pflanzenf. ii. Abt. 4, 56 (1888); Bak. Brom. 163 (1889); Mez in DC. Mon. Phan. ix. 869 (1896); O. Ktze. Rev. Gen. iii. 304 (1898); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 245 (1917); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930); Herter, Florula Urug. 45 (1930); L. B. Smith, Not. Brom. in Ostenia, 361 (1933). *Tillandsia Nappii* Lorentz & Niederlein in Roca Exped. Rio Negro, ii. 282 (1881).—Pl. IV, figs. 13–15.

BOLIVIA: Potosi: dry *Mimosa*-forest formation, alt. 2600 m., 1927, *C. Troll 3369* (Mun). URUGUAY: 1890, *André K 326* (G). ARGENTINA: Salta: Cerro San Bernardo, 1919, *Hauman 1567* (G); dept. Guachipas, Alemania, alt. 1300 m., 1929, *Venturi 9977* (G, US); Tucuman: dept. Trancas, Tapia, 1919, *Schreiter 1029* (G); same, alt. 700 m., 1920, *Venturi 1178* (Ost); dept. Trancas, Vipos, 1921, *Schreiter in hb. BA 27/2336*, *27/2348* (G); same, alt. 786 m., 1923, *Schreiter 2032* (Ost); Catamarca: Cerro del Arenal, 1917, *Jörgensen 1772* (G, US, Mo, Ost); La Rioja: dept. Famatina, Guanchin, alt. 1600 m., 1928, *Venturi 8096* (G); Córdoba: Estancia Germania near Cordoba, 1874, *Lorentz 122* (BM, type; B, phot. G, NY); Chacra de La Merced, 1881, *Hieronymus* (NY, S); Los Paredones near Capilla del Monte, alt. ca. 1000 m., 1918, *Osten 13480*, *13481* (Ost); same, 1922, *Castellanos 1570* (G); Valle de Los Reartes, 1919, *Castellanos* (G, US, FM, Ost).

The original description of this species was drawn up by Baker and was based directly on the exsiccatae name on *Lorentz 122* from Cordoba. Grisebach republished the name a year later and based it on two collections. Then Lorentz and Niederlein distinguished these collections as separate species but gave the new name, *T. Nappii*, to that collection which was already the type of *T. myosura*. Thus *T. Nappii* must inevitably fall into synonymy and whoever wishes to consider the two collections distinct species must propose another name for the second collection.

From an examination of the material cited above it appears that the distinctions proposed by Lorentz and Niederlein are of no value. The character of glabrous leaf-sheaths is often striking but may show transition to the lepidote type on a single plant. The indument on the scape is extremely variable and shows no correlation with other characters. It is a result of age and probably of habitat also.

The specimens with glabrous leaf-sheaths approach *T. retorta* in habit, and may possibly represent hybrids with the latter species.

35. **Tillandsia** (§ **Diaphoranthema**) **retorta** Griseb. Plant up to 15 cm. long when in flower but usually only half that long: stems many from a single point, forming a dense globose mass, usually much branched, 2–8 cm. long: roots present: leaves distichous, 3–5 cm. rarely up to 7 cm. long, densely cinereous-lepidote; sheaths suborbicular, prominently nerved with broad nerveless margins, normally glabrous with a ciliate margin of elongate scales but occasionally as lepidote as the blades, imbricate and making the stem appear 3–5 mm. thick; blades recurved and contorted, slender, terete, acuminate-pungent, barely over 2 mm. thick, prominently nerved when dry: scape terminal or pseudo-axillary, from almost none to 55 mm. long, but usually quite short, slender, densely lepidote, naked: inflorescence 1–2-flowered, densely cinereous-lepidote; rhachis produced behind the terminal flower; floral bracts erect, ovate, acute or acuminate, 10–12 mm. long, equaling or exceeding the sepals, slightly more than twice as long as the internodes in the several-flowered specimens, prominently nerved: flowers subsessile; sepals lance-oblong, acute, 10 mm. long, thin, prominently nerved, lepidote, much connate posteriorly; petals yellow (Venturi!), blade distinct, narrowly elliptic, 6 mm. long, much firmer than the claw; stamens deeply included, exceeding the pistil; ovary ellipsoid, stipitate, slightly shorter than the style, stigma capitate: capsule slenderly cylindric, abruptly short-beaked, 25–30 mm. long.—Epiphytic; northern Argentina.—Griseb. ex Bak. in Journ. Bot. xvi. 238 (1878); xxv. 213 (1887); Griseb. Symb. Argent. in Goett. Abh. xxiv. 334 (1879); Bak. Brom. 162 (1889); Mez in DC. Mon. Phan. ix. 868 (1896); O. Ktze. Rev. Gen. iii. 304 (1898); Spegazzini, Nov. Add. in An. Mus. Nac. B. A. ser. 2, iv. 171 (1902); Macloskie Rep. Princeton Univ. Exped. Patagonia, viii. 294 (1904); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat.

B. A. xxix. 247 (1917); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 506 (1933). *T. caespitosa* Gill. ex Bak. in Journ. Bot. xvi. 238 (1878), in synon. non LeConte. *T. Nappii* var. *Darwinii* Lorentz & Niederlein in Roca Exped. Rio Negro, ii. 282 (1881); Castellanos Brom. Arg. i., in Com. Mus. Nac. Hist. Nat. B. A. ii. 143 (1925).—Pl. IV, fig. 20.

ARGENTINA: Tucuman: dept. Trancas, between Tapia and Cadillal, alt. 700 m., 1920, *Venturi 1029 in part* (G); same, 1924, *Schreiter 4165* (Castellanos!); Vipos, alt. 786 m., 1923, *Schreiter 1368 in part* (Ost); same, 1921, *Schreiter 6599 in part* (Castellanos!); same, alt. 850 m., 1921, *Venturi 1371* (US); between Tapia and Raco, 1920, *Schreiter 1368 in part* (Castellanos!); Tapia, 1923, *Schreiter 6599 in part* (Castellanos!); Trancas, 1924, *Venturi 1029 in part; 2492; 3522* (Castellanos!); Santiago del Estero: 1910, *Willis* (US); Córdoba: Estancia Germania near Córdoba, *Lorentz 125* (BM, TYPE); near Córdoba, 1871, *Lorentz 70* (US); 1877, *Hieronymus 484* (US); Chacra de La Merced near Córdoba, 1881, *Hieronymus* (G, B, NY, SP); Sierra de Córdoba, 1875–6, *Hieronymus 348* (B); Cuesta de Las Minas, Potrero de Garay, Anisacate, 1895, *Kurtz 8626a* (NY, MN Rio); Dean Funes, 1916, *Sanzin 1158* (Ost); Sierra Chica, La Falda, alt. ca. 1000 m., 1918, *Osten 13458* (Ost); same, Los Paredones near Capilla del Monte, *Osten 13479* (Ost); same, Valle Hermoso, alt. ca. 950 m., *Osten 13484* (Ost, S); same, Rio Pintos, alt. 1000 m., *Osten 13493* (Ost); indefinite, 1877, *Hieronymus* (BM); *9; 146* (Mez!); *Lorentz 97* (Mez!); *Kurtz 1152, 6607* (Mez!); San Luis: Alto de las Jarillas, 1882, *Galander 25* (B); Quebrada del Salado near La Bebida de Las Vacas, 1882, *Galander* (BM, S); Mendoza: 1825, *Gillies* (K, type of *T. caespitosa;* Cam, G); San Rafael, Cañada Seca, 1921, *Ruiz in hb. BA 25/1862* (G); Buenos Aires: Laguna Salada de Narracó, 1879, *Lorentz & Niederlein* (B, type of *T. Nappii* var. *Darwinii;* phot. G); near Carmen de Patagones, *Spegazzini* (Spegazzini!); La Pampa: Naicó, 1931, *Monticelli* (Castellanos!); Indefinite: *Miers 1366* (BM).

Tillandsia retorta apparently forms frequent hybrids with other species. The probability of its crossing with *T. myosura* has already been noted. In hb. Osten, *Venturi 1371* from Vipos, Tucuman, is intermediate between the two having leaf-sheaths like typical *T. retorta* but a 3-flowered inflorescence and sepals that are sometimes equally subfree and sometimes posteriorly connate. Another specimen in hb. Osten, *Osten 13478,* was collected between specimens of *T. retorta* (*Osten 13479*) and *T. Castellani* (*Osten 13474*) and is evidently a hybrid of the two.

36. **Tillandsia** (§ **Diaphoranthema**) **andicola** Gillies. Plant up to 3 dm. long when in flower: stem more than 2 dm. long, much more than half the total length of the plant and several times longer than the leaves thus giving the plant a very distinctive habit, branching particularly near the apex: roots present: leaves rather laxly distichous or polystichous, up to 6 cm. long but usually only about 4 cm., densely subappressed-lepidote with basally produced cinereous scales; sheaths about 5 mm. apart on the stem, making the stem appear 3–4

mm. thick, suborbicular, much broader than the blades, several-nerved with a broad nerveless margin, ciliate with elongate scales, usually lepidote except for the extreme base, occasionally with a narrow glabrous strip next the margin or wholly glabrous in extreme age; blades recurving and more or less contorted, 2 mm. thick but acuminate and pungent, terete, strongly nerved when dry: scape terminal or pseudo-axillary, from almost none to 6 cm. long, densely lepidote, naked or with a single lanceolate involute acuminate lepidote bract: inflorescence 1- or rarely 2-flowered, densely lepidote; rhachis produced behind the terminal flower; floral bract lance-ovate, acuminate, up to 14 mm. long, exceeding the sepals, twice as long as the internode and not concealing the rhachis in the 2-flowered specimen, prominently nerved, not at all keeled, closely enfolding the calyx: flowers subsessile; sepals lance-oblong, acute, 11 mm. long, prominently nerved, joined posteriorly for half their length; petals narrow; stamens deeply included, exceeding the pistil.—Northwestern Argentina.—Gillies ex Bak. in Journ. Bot. xvi. 239 (1878); xxv. 213 (1887); Bak. Brom. 161 (1889); Mez in DC. Mon. Phan. ix. 871 (1896); Macloskie, Rep. Princeton Univ. Exped. Patagonia, viii. 293 (1904); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 242 (1917); Castellanos, Brom. Arg. iv., *in* An. Mus. Nac. Hist. Nat. B. A. xxxvii. 498 (1933).—Pl. IV, fig. 18.

ARGENTINA: CATAMARCA: Cuesta de La Chilca, Agua de La Chilca, 1930, *Schreiter 1136* (G); MENDOZA: Andes of Mendoza, *Gillies* (K, TYPE; Cam, G); Crucesita, 1906, *Carette 1186* (G).

37. **Tillandsia** (§ **Diaphoranthema**) **Landbeckii** Phil. Plant up to 3 dm. long when in flower: stems densely massed, usually much branched, up to 2 dm. long, slender: roots present in small specimens, but apparently often lost in later development: leaves laxly distichous, 6–12 cm. long, densely subpruinose-lepidote with fine cinereous scales; sheaths elliptic, thin, few-nerved, densely lepidote except at the extreme base, 10–15 mm. long, laxly imbricate making the stem appear 2–4 mm. thick; blades more or less spreading, linear, terete, 1–1.5 mm. thick, soft with a weak point: scape terminal, erect, always prominent, up to 10 cm. long, 1 mm. or less in diameter, densely cinereous-lepidote; scape-bracts 2 or 3, immediately below the inflorescence, linear-lanceolate, acuminate or caudate-appendaged, densely lepidote: inflorescence 1–2-flowered; floral bracts like the scape-bracts but smaller, about equaling the sepals, pink (Murphy!) drying to violet: flowers subsessile, the second when present very close to the first; sepals elliptic, acute, 10 mm. long, thin, prominently

nerved, sparsely lepidote, equally subfree; petals ligulate, obtuse, yellow when dry; stamens deeply included, slightly exceeding the pistil; ovary about as long as the style: capsule slenderly cylindric, abruptly short-beaked, 22 mm. long.—Terrestrial and epiphytic; along the coast from Ecuador to northern Chile.—Phil. in Linnaea, xxxiii. 248 (1864), An. Univ. Chile, lix. 323 (1881); Cat. Pl. Chil. 279 (1881); Mez in DC. Mon. Phan. ix. 872 (1896); Reiche, Pflanzenverbreit. Chile in Engl. & Drude, Veg. d. Erde, viii. 178 (1907); I. M. Johnston in Contrib. Gray Herb. lxxxv. 22 (1929); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930); Reiche & Looser, Geog. Bot. Chile, 295 (1934). *T. recurvata* aut. non L.; Bak. in Journ. Bot. xvi. 239 (1878), in part; Brom. 162 (1889); L. B. Smith ex I. M. Johnston in Contrib. Gray Herb. xcv. 31 (1931).—Pl. IV, fig. 17.

ECUADOR: without definite locality, *Lehmann* (Mez!). PERU: Ica: foggy crests of San Gallan Island, clinging to lee-sides of rocks, alt. 300–440 m., 1919, *R. C. Murphy 3468* (G, Brooklyn); Viejas Island, on crumbling rocks at summit, 1919, *R. C. Murphy 3221* (Brooklyn). CHILE: Antofagasta: dept. Taltal, on shrubs and cactus on summit ridge, Cerro Perales ("Cerro del Hueso Parado" of Philippi) near Taltal, ca. lat. 25° 24′ S., alt. ca. 1000 m., 1925, *I. M. Johnston 5624* (G); Atacama: dept. Copiapó, vicinity of Caldera, Cerros de Copiapó, 1885, *E. E. Gigoux 59* (G); hills north of Copiapó, alt. ca. 800 m., 1925, *I. M. Johnston 5022* (G); Coquimbo: Illapel, 1862, *Landbeck* (G, part of type); same, *Philippi 969* (Bo); Choapa, *Philippi* (BM, DH).

38. **Tillandsia** (§ **Diaphoranthema**) **recurvata** L. Plant somewhat variable, 4–23 cm. long when in flower: stems densely massed, simple or few-branched, 1–10 cm. long, typically much shorter than the leaves but occasionally about equaling them: roots present: leaves distichous, 3–17 cm. long, densely pruinose-lepidote with cinereous or ferruginous scales; sheaths elliptic-ovate, thin, many-nerved with a broad hyaline nerveless margin, the extreme base glabrous, elsewhere densely lepidote and with a ciliate margin of elongate scales, imbricate and completely concealing the stem; blades typically recurved, sometimes only spreading or even erect, linear, terete, 0.5–2 mm. in diameter, rather soft with a weak point: scape terminal, always prominent, up to 13 cm. long, ca. 0.5 mm. in diameter; scape-bracts linear-lanceolate, lepidote, 1 or very rarely 2 immediately below the infloresecnce, sometimes one next the inflorescence and one remote: inflorescence typically 1–2- rarely up to 5-flowered, dense; floral bracts like the scape-bracts but smaller, typically equaling or longer than the sepals but often distinctly shorter, several-nerved, densely lepidote: flowers erect, subsessile; sepals lanceolate, usually acute, 4–9 mm. long, equally subfree, thin with 3 or more prominent nerves, typically glabrous but towards its southern limits somewhat

lepidote in an increasing proportion of specimens; petals narrow, pale violet or white, blade narrowly elliptic, obtuse; stamens deeply included, exceeding the pistil: capsule slenderly cylindric, abruptly short-beaked, up to 3 cm. long.—Terrestrial and epiphytic; southeastern United States to northern Argentina and Chile.—Sp. Pl. ed. 2, 410 (1762); Lam. Encycl. i. 618 (1785); Sw. Obs. Bot. 121 (1791); Willd. Spec. ii. 14 (1799); R. & P. Fl. Peruv. iii. 42, t. 271, fig. a (1802); Michx. Fl. Bor.-Am. i. 195 (1803); Ait. Hort. Kew, ed. 2, ii. 204 (1811); Pursh, Fl. Sept.-Am. i. 217 (1814); HBK. Nov. Gen. i. 291 (1816); Meyer, Fl. Esseq. 146 (1818); Nutt. Gen. i. 208 (1818); Lk. Enum. i. 308 (1821); LeC. in Ann. Lyc. Nat. Hist. N. Y. ii. 132 (1828); R. & S. Syst. vii. 1202 (1830); Gris. Fl. Br. W. Ind. 598 (1864); Chapm. Fl. South. U. S. 472 (1860); Bak. in Journ. Bot. xvi. 239 (1878); xxv. 213 (1887); Benth. & Hook. Gen. iii. 669 (1883); Hemsl. Biol. Centr.-Am. iii. 321 (1884); Wittm. in Engl. & Prantl, Pflanzenf. ii. Abt. 4, 56 (1888); Bak. Brom. 162 (1889); Mez in Mart. Fl. Bras. iii. pt. 3, 609 (1894); Mez in DC. Mon. Phan. ix. 872 (1896); Small, Fl. s. e. U. S. 245 (1903); W. J. Birge, Bull. Univ. Texas, no. 194 (1911); Boldingh, Fl. Ned. W.-I. 144 (1913); Hassler, Cons. & Jard. Bot. Genève, xx. 335 (1919); Britton & Wilson, Bot. P. Rico, v. 141 (1923); Herter, Fl. Urug. 45 (1930); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930); Standl. Field Mus. Pub. Bot. iii. 222 (1930); Castellanos, Physis, x. 88 (1930); An. Mus. Nac. Hist. Nat. B. A. xxxvii. 506 (1933). *Viscum Caryophylloides minus foliis pruinae instar candicantibus, flore tripetalo purpureo semine filamentoso* Sloane, Cat. 77 (1696); Ray, Hist. Pl. Suppl. 406 (1704); Sloane, Hist. i. 190, t. 121, fig. 1 (1707). *Renealmia foliis subulatis scabris; pedunculis unifloris* Royen, Lugd.-Bat. 25 (1740). *R. recurvata* L. Sp. Pl. 287 (1753), excl. var. β. *Tillandsia parasitica parva, pruinosa, scapo tenui bifloro* Browne, Jam. 194 (1756). *T. uniflora* HBK. Nov. Gen. i. 290 (1816). *Diaphoranthema uniflora* Beer, Brom. 154 (1857). *D. recurvata* ibid. 156. *Tillandsia monostachys* Gill. ex Bak. in Journ. Bot. xvi. 239 (1878), in synon., non L. *T. recurvata* forma *genuina* André, Brom. Andr. 65 (1889); formae *elongata, major, minor, contorta, caespitosa, brevifolia, argentea* ibid. *T. recurvata* var. *ciliata* E. Morr. ex Mez in Mart. Fl. Bras. iii. pt. 3, 610 (1894); var. *contorta* André ex Mez, ibid. 611; var. *minuta* Mez, ibid. *Phytarhiza ciliata* E. Morr. ex Mez in Mart. Fl. Bras. iii. pt. 3, 610 (1894), in synon. *T. cordobensis* Hieron. sensu Hassler, Fl. Pilc. in Trab. Mus. Farm. B. A. xxi. 41 (1909), non Hieron.—BALL MOSS; BUNCH MOSS; OLD MAN'S BEARD; NIDOS DE GUNGULEN (Porto Rico); BARBA DIE KADOESJI and MARIE DIE PAALOE (Dutch West Indies).

UNITED STATES: Florida: Duval Co.: Jacksonville, *Curtiss 2849* (G, BM, NY); *4141* (DH, NY); *5054* (G, NY); St. Nicolas, *Lighthipe 624* (NY); Alachua Co.: Gainesville, *Garber* (G); *S. J. Knight 2* (NY); Volusia Co.: De Land, *G. B. Grant 1223* (NY); Lake Co.: Eustis, *Nash 1372* (G, NY); *Underwood 1352* (NY); Orange Co.: Orlando, *Canby* (G); *Harper 9* (G, NY); *Moldenke 5329* (NY); Brevard Co.: Merritts Island, *Curtiss 5772* (G, NY, Pom); Okeechobee region, *Fredholm 6058* (G); Pasco Co.: Odessa, *Blanton 6924* (Bailey); Pinellas Co.: Dunedin, *Tracy 6749* (G, NY); Lee Co.: Fort Myers, *Hitchcock 345* (G, NY); La Costa Island, *J. H. Simpson 360* (DH); Dade Co.: Miami, *Moldenke 535* (NY, S); Sykes Hammock, *Small, Mosier & Simpson 5776* (NY, S); Nixon-Lewis Hammock, *Small & Mosier 5886* (NY, S); Monroe Co.: Long Key, *Tracy 7521* (G, BM, NY); Key Largo, *Small & Carter 3117* (NY); indefinite: *Chapman* (NY); *Rugel 362* (NY, Pom); *Leavenworth* (G, NY); Texas: Travis Co.: Austin, *G. W. Letterman* (DH, NY, FM); *Rose & Russell 24130* (G); *H. H. York 52* (DH); Blanco Co.: Blanco, *E. J. Palmer 33962* (Mo, G, NY); Hays Co.: San Marcos, *Trelease* (Mo); Val Verde Co.: Devil River between Ozona and Comstock, *Ferris & Duncan 3037* (NY, Mo, DH, Pom); Brewster Co.: Chisos Mts., *C. H. Mueller 8576* (G, FM); *Ferris & Duncan 2801* (Mo, DH, NY); *Moore & Steyermark 3198* (G, NY); Comal Co.: New Braunfels, *Lindheimer 226* (G); *539* (G, NY, FM, Mo, Pom); *1200; 1201* (G, NY, FM, Mo, BM); Bandera Co.: *Reverchon 950* (Mo); Bexar Co.: San Antonio, *B. F. Bush 1271* (NY, Mo); *J. Clemens 144* (NY); *Farlow* (G); *G. Jermy* (NY); Uvalde Co.: *Milligan* (US); Karnes Co.: Gillett, *Munz 1467* (Pom); Victoria Co.: Victoria, *E. J. Palmer 9069* (S, Mo); Bee Co.: Beeville, *Bencke 5346* (G, FM); Nueces Co.: Corpus Christi, *A. Heller 1400* (NY); *H. Ravenel 172* (NY, Mo); Cameron Co.: Brownsville, *Ferris & Duncan 3194* (Pom, DH, Mo); *H. C. Hanson 479* (NY); Arizona: Santa Cruz Co.: Atascosa Mts., 20 miles n. w. of Nogales, *Phillips* (US); Patagonia Mts., *Bartram & Peebles 10611* (US). MEXICO: Tamaulipas: San Fernando, *Berlandier 818; 2238* (G); Matamoros, *Gregg* (G); Jaumave, *Rozynski 120* (FM); *251* (G, FM); Nuevo Leon: Monterrey, *Gregg* (G); near Pueblo Galeana, *Mueller 325* (G); Coahuila: Jimulco, *Pringle 219* (G); Saltillo, *E. Palmer 428* (G); Chihuahua: Mapula Mts., *Pringle 801* (NY, Mo, FM, BM, S); Sonora: Alamos, 1890, *E. Palmer 372* (G); Cochuto, *Hartman 74* (G, FM); Baja California: Playa Maria, *Anthony 96* (G, NY, S, FM, Mo, Pom, DH); between San Lucas and Todos Santos, *G. F. Ferris* (DH); Loreto, *W. S. W. Kew* (US); Sinaloa: Labrados, *Ferris & Mexia 5121* (DH); Villa Union, *Rose, Standley & Russell 13978* (US, NY); Mazatlan, 1849, *Strickland* (BM); Durango: Durango, *E. Palmer 640* (G, NY, FM, Mo, UCal, BM, Bo); Zacatecas: Santa Rosa and Cedros, *Kirkwood 42* (G); near Cedros, *Kirkwood 200* (FM); *Lloyd 55* (G, Mo); San Luis Potosi: San Luis Potosi, *Parry & Palmer 872 1/2* (G); *Schaffner 225 1/2* (NY, FM); *530* (G); Charcas, *Lundell 5479* (G); Vera Cruz: Orizaba, *Mueller 1756* (G, NY); Panuco, 1910, *E. Palmer 372* (G, Mo); Zacuapan, *Purpus 8223* (G, NY, Mo); Perote, *Schiede & Deppe* (BM); Vera Cruz, *Houston* (Cam); San Francisco near Vera Cruz, *C. L. Smith 1325* (G); Guanajuato: Guanajuato, *Duges* (G); Aguascalientes: Aguascalientes, *Deam 156* (G, FM); *J. G. Smith 183* (Pom, Mo); Nayarit: Santiago Ixcuintla, *Ortega 6149* (G, DH); Jalisco: Tuxpan, *Mexia 1029-a* (G, NY, FM, Mo, BM); Colima: Manzanillo, *Trelease* (Mo); Michoacan: Chapultepec, *Brandegee* (UCal); Morelia, *Arsène 5361* (Mo); Mexico: Valley of Mexico, *Bourgeau 96* (G, S); Federal District: Mexico City, *Lemmon* (UCal); Morelos: Cuernavaca, *Fröderström & Hultén 62; 159* (S); Puebla: San Luis Tultitlanapa, *Purpus 3394* (G, NY, FM, Mo, BM); Puebla, *Arsène 47* (S, Mo); *1298; 1840* (G, Mo); *2194m* (BM); *10124* (US); Guerrero: Chilpanzingo, *Humboldt & Bonpland* (P, type of *T. uniflora;* phot. G); Oaxaca: Ocotlán, *Conzatti & Gonzalez 1277* (G); Valle de Oaxaca, *Conzatti & Gonzalez 1168* (G);

Yucatan: Silam, *Gaumer 659* (G, NY, FM, Mo, BM); San Anselmo, *Gaumer 1912* (G, S, FM, Mo, DH, BM, BA); Chichankanab, *Gaumer 1913* (FM); Merida, *Schott 35* (BM, FM); Izamal, *Greenman 401* (FM); Indefinite: *Berlandier 191* (G); *367* (BM); *1451* (G). SALVADOR: San Salvador: San Salvador, *Caldéron 1505* (G, NY). NICARAGUA: Masaya: Santiago Volcano, Masaya, *Maxon 7672* (US, NY). BAHAMAS: Eleuthera, *Britton & Millspaugh 5579* (NY, FM); Andros, *Brace 5051* (FM); *Northrop 617* (G, NY, FM); *Small & Carter 8652* (NY, FM); Cat Island, *Hitchcock* (FM); Watling's Island, *Britton & Millspaugh 6147* (NY, Mo); Great Exuma, *Britton & Millspaugh 3011* (G, NY, FM); Acklin's Island, *Brace 4450* (G, NY, FM); Inagua, *Nash & Taylor 914* (NY, FM). CUBA: Isla de Pinos: Sierra de Casas, *Ekman 12566* (S); Columbia, *Britton & Wilson 15634* (NY, FM); Caballos, *Jennings 194* (NY); Pinar del Rio: Pinar del Rio, *Palmer & Riley 77* (NY); Rio Portales, *Shafer 11196* (G, NY, Mo, FM); Los Palacios, *Shafer 11907* (NY); Sumidero, *Shafer 13379* (NY); Buenaventura, *Wilson 9353* (NY); Sierra de Anafe, *Wilson 11393* (NY); Havana: Sierra del Anafe, *Ekman 1122* (S); Guanabacoa, *Curtiss 586* (G, NY, FM, Mo, BM); Anafe, *Ekman 238* (G, FM, S); Arroyo Apulo, *Leon 637* (NY); Guines, *Van Hermann 190* (NY, FM); Santiago de las Vegas, *Van Hermann 392* (NY, FM); *704* (NY, FM, BM); Matanzas: Matanzas, *Britton 240* (NY); Jumury, *Rugel 245* (NY, BM); Santa Clara: Rio San Juan, *Britton, Earle & Wilson 5848* (NY); Cieneguita, *Combs 580* (G, NY, FM, Mo); Soledad, *Jack 6220* (G, BA); *6268* (G); *6366* (G, S, FM); *6386; 6472* (G); Las Vegas de Matagua, Buenos Aires, *Jack 8739* (S); Sancti Spiritus, *Shafer 12091* (NY); Rinco to Banao, *Shafer 12320* (NY); Camaguey: Loma de Loro, *Shafer 2642* (G, NY, FM, BM); Cayos Canal Nuevo, *Shafer 2665* (G, NY, FM, BM); Oriente: *Wright 687* (G, NY, Mo, S); *688* (G); Santiago de Cuba, *Ekman 8013* (G, S); *Millspaugh 1016* (FM); Holguin, *Shafer 1257* (NY); Guantánamo, *Ekman 2851* (S); San Juan Hill, *Shafer 12423* (NY, Mo). JAMAICA: 1687–9, *Sloane* (BM, type); 1780–2, *Shakespear* (BM); *Swartz* (S); Santa Cruz Mts., *Britton 1322* (NY); Luana Point, *Britton 1518* (NY); Kingston, *S. Brown 388* (NY); Kingston to Waureka, *Maxon 10526* (S); Balaclava, *Perkins 1417* (G); Heathshire Hills, *Harris & Britton 10511* (FM). HAITI: Grande Cayemite, *Eyerdam 322* (G, FM); Navassa Island, *Rehder 21* (G); St. Michel de l'Atalaye, *Leonard 7178a* (US); Bombardopolis, *Leonard 13462* (G, US); Port Margot, *Nash 902* (NY); San Michel, *Nash & Taylor 1402* (NY); Jaimel, *Xavier* (BM). SAN DOMINGO: Amouroux, *hb. Nolte* (BM); Azua, *Rose, Fitch & Russell 3840* (NY). PORTO RICO: Desecheo Island, *Britton, Cowell & Hess 1576* (NY); Mona Island, *Britton, Cowell & Hess 1813* (NY); *Stevens 6442* (NY); Mayaguez, *Cowell 506* (NY, FM); *Sintenis 265* (G, NY, Mo, FM, BM, S); Coarmo, *Goll, Cook & Collins 752* (NY); *Heller 512* (NY, FM); *Sintenis 3023* (NY, Trin); Cabo Rojo, *Heller 4427* (G, NY, FM, Mo); *Stevens 2260* (NY); Guayama, *Kuntze 552a* (NY); *Underwood & Griggs 427* (NY); Santa Rita, *Stevenson 2256* (G, FM). LESSER ANTILLES: St. Croix: *Ricksecker 272* (G, NY); *Bentzen 6* (S); *Hornbeck* (S); *Thompson 968* (S); St. Martin: *Rijgersmaa* (S); *Boldingh 2620* (NY); St. Bartholomew: *Euphrasen* (S); *Forsström* (S); St. Kitts: *Britton & Cowell 461* (NY); Nevis: *Tobin* (BM); Antigua: *Gregory* (BM); *Rose, Fitch & Russell 3303* (NY); *Shafer 33* (NY); *Bailey 177* (Bailey); Montserrat: *Shafer 69* (NY, FM); Guadeloupe: *Duss 3401* (NY); Martinique: *Duss 992a* (G, NY, FM, Mo); *Hahn 1029* (US); *1052* (BM); *1555* (BM, S); Bonaire: *Boldingh* (NY); Curaçao: *Britton & Shafer 3024* (NY, FM); *Curran & Haman 57* (G). VENEZUELA: Bolivar: Isla Degrero, near Ciudad Bolivar, *Bailey 1780* (Bailey); Nueva Esparta: Coche Island, *J. R. Johnston 14* (G); Margarita Island, *J. R. Johnston 219* (G, NY); Sucre: Cristobal Colon, *Broadway 815* (G, NY); Distrito Federal: Caracas, *Allart 12* (NY); *Bailey 6* (G, Bailey); *Pittier*

9872 (G, NY); *11288* (NY); Cabo Blanco near La Guaira, *Curran & Haman 932* (G, US); *960* (G); Aragua: Colonia Tovar, *Fendler 1534* (G, NY, Mo); Maracay, *Vogl 1049* (Mun); Carabobo: Puerto Cabello, *André 161 in part* (G, NY, FM); Zulia: Lagunillas, *Jahn 961* (G); Maracaibo to Machiques, *Pittier 10544* (G). COLOMBIA: Magdalena: Tenerife, *André 161 in part* (G, NY, FM); Norte de Santander: Toledo, *Killip & Smith 20122* (G, NY, FM, S); Santander: Bucaramanga, *Killip & Smith 16391* (G, NY, FM, BM); Antioquia: Medellin, *Archer 384* (G, US); *Toro 79* (NY); Cundinamarca: Fusagasuga, *André 161 in part* (FM); Quetamé, *hb. nac. Colombia* (G, US); La Esperanza, *Ariste Joseph B 85* (G); Pandi, *Pennell 2832* (G, NY); El Valle: Cali, *Lehmann 7767* (FM); La Paila, *Holton 154* (NY); Dagua, *Killip & Hazen 11081* (G, US, NY); Palmira, *Pennell & Killip 6172* (G, US, NY). ECUADOR: Imbabura: Rio Chota, *Lehmann 646* (BM); Otavalo, *Hitchcock 20838* (G, NY). PERU: Piura: Cerro Prieto, *Haught 215* (NY, BM, S); Huanuco and Junin: *Ruiz & Pavon* (BM); Lima: Chosica, *Macbride 2880* (G, FM); Matucana, *Macbride & Featherstone 457 in part* (G, FM, S); Obrajillo, *Mathews 650 in part* (G). BOLIVIA: El Beni: Trinidad, alt. 250 m., 1926, *Werdermann 2530* (S); La Paz: Sorata, *Mandon 1177* (G, NY, S); *R. S. Williams 2424* (NY, BM); Apolo, *R. S. Williams 1485* (NY, US, BM); Illimani, *Buchtien 4143* (NY); Santa Cruz: Santa Cruz, *Steinbach 7452* (BM, FM, S, Mo). BRAZIL: Pernambuco: Recife, *Pickel 14489* (SP); Alagoas: Paulo Affonso Falls, *Chase 7809* (US); Minas Geraes: Lagoa Santa, *Warming* (Ko, type of var. *minuta;* phot. G); *Hoehne 6418*, *6419* (MN Rio); Sabara, *Hoehne 6891*, *6892* (MN Rio); Paraisopolis, *Hoehne 19181* (SP); Rio de Janeiro: Barra do Pirahy, *Hoehne & Gehrt 17329* (G, SP); São Paulo: Pirajussára, *A. Gehrt 12379* (G, SP); Campinas, *Mosén 375* (S); *G. Gehrt 3532* (G, SP); Itapira, *Hoehne 20400* (G, SP); Serra Negra, *Hoehne 20707* (G, SP); Atibaia, *Lindberg 563* (S); São Paulo, *Löfgren 12380* (G, SP); Serra de Caracol, *Mosén 1736; 1737; 4441* (S); Paraná: Villa Velha, *Dusén 2763* (MN Rio); Porto Amazonas, *Dusén 9530* (NY); Rio Grande do Sul: Porto Alegre, *Lindman A 255; A 1631a* (S); Piratinhý, *Lindman A 915* (S); Colonia Santo Angelo, *Lindman A 915b* (S); Santa Maria, *Lindman A 1631b* (S). PARAGUAY: Asuncion, *Balansa 618a* (Bo); *Lindman A 1855* (S); Ypacaray, *Hassler 1772* (NY); *Fiebrig 50* (G, FM, BM); Villa Rica, *Jörgensen 3964* (NY, FM, S, DH, Mo); *Lindman A 1777* (S); Pirapó, *Lindman A 1779* (S); San Antonio, *Lindman A 1783; A 1785* (S); central Paraguay, *Morong 492a* (G, NY, Mo, BM); San Bernardino, *Osten 8152b* (G, Ost); *8152* (Ost, S); *8922a* (Ost); Villa Encarnacion, *Rojas* (G, Ost); Carapeguá, *Rojas 203* (G, Ost); Rio Pilcomayo, El Chaco, *Lindman A 1895 1/2* (S); *Morong 292b; 876; 1085* (NY). URUGUAY: Artigas: Arapey, *Osten 3291* (Ost); Salto: *Schroeder* (Ost); Cerro Largo: Palleros, *Herter* (Ost, S); Soriano: Mercedes, *Osten 2943; 3054; 3120* (Ost); Treinta y Tres: Yerbal, *Herter 83393* (G); Minas: Arequita, *Herter 88899* (G, Mo). ARGENTINA: Formosa: *Jörgensen 3395* (G, Mo, US); Jujuy: Laguna de la Brea, *Fries 414* (G, S); Salta: San Carlos, *Venturi 7292* (US); *7293* (G, US); Tucuman: Naranjal, *Schreiter 749* (Ost); Yerba Buena, *Schreiter 27/2363* (G); *Venturi 268* (G, S, Ost); El Duraznito, *Venturi 2797* (G, US, FM, S); *2798* (G, S, Ost); Santa Fe: Sante Fe, *Castellanos 24/1218* (G); Buenos Aires: Buenos Aires, *Gillies* (K, type of *T. monostachys;* BM, G); *Tweedie* (BM); San Fernando, *Pennington* (G, SP). CHILE: *Cuming* (Mez!).

The typification of *Tillandsia recurvata* is quite simple, since Linnaeus had no material of his own when he originally published it as *Renealmia recurvata,* and gave but two references. These are based on the same plant since the Royen reference is nothing but a repetition of the Sloane one.

It has not been possible to check the record of this species from Chile and there is some doubt if it actually occurs there.

T. recurvata shows considerable variation from the West Indian form which is taxonomically typical to the form in the extreme southern part of its range. This southern form is smaller and more slender in habit, and has lepidote sepals which often exceed the bracts. Usually it is 1-flowered. Although the difference between the extremes is striking, the intergradations are manifold and it seems impossible to define any satisfactory categories within the species.

Mez has cited *Tillandsia Bartramii* Ell. under the synonymy of both *T. recurvata* and *T. tenuifolia.* The type of *T. Bartramii* in the Charleston Museum is obviously identical with *T. tenuifolia* and its supposed relation to *T. recurvata* must be the result of misinterpretation.

Venturi 2801 from El Duraznito, Tucuman, Argentina, is evidently a hybrid of *T. recurvata* and *T. bandensis* both of which occur in the same locality. The specimens of that number show various degrees of variation between the two species in the density of the inflorescence and its amount of indument.

39. **Tillandsia** (§ **Diaphoranthema**) **capillaris** R. & P. Plant very variable in both size and form, up to 16 cm. long when in flower: roots present: stems many from a single point, densely massed, simple or branched: leaves distichous, mostly 1–4 cm. long, rarely shorter or up to 9 cm. long, densely and finely pruinose-lepidote with cinereous to ferrugineous scales; blades erect to spreading, straight or rarely contorted, linear and less than 2 mm. thick or narrowly triangular and thicker according to the form represented; sheaths usually elliptic, thin, several-nerved, densely lepidote except where covered by the next below: scape from almost none to 8 cm. long, mostly slender, always naked, glabrous or slightly lepidote toward apex, developed almost wholly after anthesis: inflorescence normally 1-flowered, rarely 2-flowered; floral bracts ovate, acute or apiculate, thin with 3 or more strong nerves, densely lepidote to glabrous, usually equaling or exceeding the sepals: flowers subsessile; sepals lanceolate, acute or obtuse, up to 8 mm. long, connate posteriorly; petals narrow with blade scarcely distinct, white, yellow or brown; stamens deeply included, exceeding the pistil.—Saxicolous and epiphytic; Peru and Bolivia to central Argentina and Chile.—R. & P. Fl. Peruv. iii. 42, t. 271, fig. c (1802); Spreng. Syst. ii. 23 (1825); R. & S. Syst. vii. 1201 (1830); Wittm. in Engl. & Prantl, Nat. Pflanzenf. ii. Abt. 4, 56 (1888); Bak. Journ. Bot. xvi. 238 (1878); xxv. 213

(1887); Brom. 161 (1889); Mez in DC. Mon. Phan. ix. 878 (1896); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930). *Diaphoranthema capillaris* Beer, Brom. 153 (1857). *Tillandsia lanuginosa* Gill. ex Bak. in Journ. Bot. xvi. 237 (1878), in synon. *T. capillaris* var. β. *lanuginosa* Mez in DC. Mon. ix. 879 (1896).—Huachuacsso, Huayhuaço (Peru).

This very variable species has a number of forms whose extremes are easily differentiated, but which show all degrees of intergradation in any large collection. All doubtful cases are kept under the typical form in this treatment. The following key defines the principal forms:

1. Floral bracts with at least 5 strong nerves meeting near the apex.
2. Scapes evident after anthesis and mostly exceeding the leaves.
3. Floral bracts glabrous or scantly and deciduously lepidote: scapes conspicuously pseudo-axillary.
4. Leaves slender and elongate, not over 2 mm. thick, obtuse, loose and spreading . . . . a. Forma *typica*
4. Leaves short and stout, mucronate, appressed and ascending so that they form an almost continuous plane . b. Forma *incana*.
3. Floral bracts densely and persistently lepidote: scapes usually but not invariably terminal: leaves widely spaced so that the greater part of each sheath is uncovered . . c. Forma *cordobensis*.
2. Scapes never elongating much even after anthesis, mostly shorter than the leaves . . . . d. Forma *virescens*.
1. Floral bracts with only 3 strong nerves meeting near the apex, other nerves if any short and with free apices . . . . . . e. Forma *Hieronymi*.

a. Forma **typica**, forma nov. foliis angustis elongatisque: scapis elongatis, pseudo-axillaribus: bracteis florigeris 5- vel pluri-nervatis, glabris vel subglabris.

PERU: *Ruiz & Pavon* (BM, TYPE; phot. G); *Dombey 162 in part* (Mez!); Huanuco: Huanuco, alt. 2300 m., 1922, *Macbride & Featherstone 2035* (G, FM, US, BM); Lima: Matucana, alt. 2700 m., 1922, *Macbride & Featherstone 457 in part* (G, FM); 1914, *Rose 18661* (G, US, NY); Junin: Tarma, *Mathews 650 in part* (K); Oroya, 1919, *Kalenborn 177* (G, US); Tarma, alt. 3000–3200 m., 1929, *Killip & Smith 21785; 21940* (US, G, NY); Cuzco: Ollantaitambo, alt. 2900–3100 m., 1915, *Cook & Gilbert 550* (US); 1925, *Pennell 13659* (G, FM); Mollepata, valley of the Apurimac, alt. 2750 m., *F. L. Herrera 1206* (Herrera!); Cuzco, 1914, *Rose 19033* (US); Sicuani, alt. 3551 m., 1903, *Hicken 10* (S). BOLIVIA: La Paz: Omasuyos near Achacache, alt. 4000 m., 1858, *Mandon 1181* (BM); Cotaña to Illimani, alt. 2450 m., 1911, *Buchtien 4026* (G); Rio Abajo, Huaricana, La Paz, alt. 2700 m., 1910, *Buchtien 807* (FM); below Obraje, alt. 3300 m., *Buchtien 6383* (US); La Paz, 1918, *Buchtien 381 in part* (S); Cochabamba: Cochabamba, alt. 2700 m., 1909, *Buchtien 2416* (US, NY); Santa Cruz: Santa Cruz, alt. 600 m., 1892, *Kuntze* (NY); Tarija: San Luis, 1864, *Pearce* (BM); Escayo, alt. 3600 m., 1904, *Fiebrig 3570* (BM); Tarija, alt. 2000 m., 1932, *Cardenas 211; 215* (G). ARGENTINA: Jujuy: dept. Ledesma, Sierra de Calilagua, alt. 700 m., 1927, *Venturi 7295* (US); Quinta near Laguna de la Brea, 1901, *Fries 418* (S); Tucuman: dept. Tafi, Naranjal, 1918, *Schreiter 796* (Ost); alt. 500 m., 1923, *Schreiter 3289* (Ost); dept. Trancas, Tapia, alt. 500 m., 1918, *Schreiter 804* (Ost); alt. 680 m., 1923, *Schreiter 3292* (Ost); dept. Trancas, Vipos, alt. 800 m., 1922, *Venturi*

1903 (G, US, Ost); alt. 780 m., 1923, *Schreiter 3290* (Ost); near la Hoyada, alt. 1000 m., 1920, *Venturi 1314* (US); Trancas, 1922, *Schreiter 27/2358* (G, BA); Sierra de la Candelaria, alt. 1000 m., 1924, *Venturi 3519* (US); Quebrada de Lules, 1922, *Schreiter 27/2359* (G, BA); Tucuman, alt. 400 m., 1922, *Venturi 1970* (G, BA, S, Ost); dept. Burroyacs, Alto de las Salinas, alt. 900 m., 1922, *Venturi 1971* (US); Córdoba: La Falda, Sierra Chica, alt. 1000 m., 1918, *Osten 10578; 13459* (Ost); *13462* (Ost, S); Mendoza: foot of the cordillera near Mendoza, 1823, *Gillies* (K, type of *T. lanuginosa;* phot. G).

b. Forma **incana** (Gill.), comb. nov. *Tillandsia incana* Gill. ex Bak. in Journ. Bot. xvi. 238 (1878), in synon. *T. propinqua* var. β. *saxicola* Hieron. Ic. & Descript. Argent. 16, t. 3, fig. 4 (1885), in part. *T. capillaris* γ. *incana* Mez in DC. Mon. Phan. ix. 879 (1896).

BOLIVIA: Potosi: prov. Nor Chichas, near Chorolque, alt. 3900 m., 1931, *Cardenas 91* (G); Potosi, alt. 4000 m., 1932, *Cardenas 209* (G). ARGENTINA: Tucuman: dept. Tafi, Sierra de San Javier, alt. 1100–1200 m., 1921, *Venturi 1515* (G, US); *1516* (G); Quebrada de la Hoyada, 1921, *Schreiter 27/2356* (G, BA); dept. Trancas, Vipos, alt. 800 m., 1922, *Venturi 1917* (G, S); alt. 786 m., 1923, *Schreiter 3288* (Ost); Catamarca: dept. Andalgalá, La Junta, 1917, *Jörgensen 1582* (G, US, Mo, BA); Córdoba: *Lossen 187* (G, FM, Mo, Bailey); Quebrada del Chorro, east of los Gigantes, Sierra Chica, 1878, *Hieronymus* (B, type of *T. propinqua* var. *saxicola*); Valle Hermoso, Sierra Chica, alt. 950 m., 1918, *Osten 13486* (FM, Ost); 1917, *Osten 10579* (Ost); near Capilla del Monte, Sierra Chica, alt. 1000 m., 1918, *Osten 13466* (Ost); *13476* (Ost, S); *13477* (Ost); 1922, *Castellanos 1575* (G, BA); near La Falda, Sierra Chica, 1918, *Osten 13488; 13489* (Ost); Rio Pintos, Sierra Chica, 1918, *Osten 13496* (Ost); Mendoza: foot of the Cordillera near Mendoza, *Gillies* (K, type; phot. G).

c. Forma **cordobensis** (Hieron.), comb. nov. *Tillandsia cordobensis* Hieron. Ic. & Descript. Argent. 10, t. 3, fig. 1 (1885); Mez in DC. Mon. Phan. ix. 875 (1896); O. Kuntze, Rev. Gen. iii. 303 (1898); Hicken, Chloris Platensis, 62 (1910); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 243 (1917); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 500 (1933). *T. recurvata* L. sensu Griseb. Pl. Lorentz. in Goett. Abh. xix. 225 (1874); Symb. Argent. in Goett. Abh. xxiv. 334 (1879), non L.

BOLIVIA: La Paz: near Sorata, alt. 2600 m., 1858, *Mandon 1177 in part* (NY); Ingenio del Oro, alt. 3300 m., 1886, *Rusby 2165* (G, FM). ARGENTINA: Chaco: Colonia Benitez, 1916, *Muello* (Castellanos!); Jujuy: 1892, *Kuntze* (NY); Cuyaya, 1922, *Inostrosa 2338* (Castellanos!); dept. Capital, Cerro de los Perales, 1903, *Holmberg* (Castellanos!); Salta: Rio de San Carlos, San Carlos, alt. 1000 m., 1927, *Venturi 7290* (G, US); Cerro de Cachi, San Carlos, alt. 2000 m., 1927, *Venturi 7294* (G); dept. Guachipas, Alemania, alt. 1400 m., 1929, *Venturi 9985* (G); Tucuman: Anfama, alt. 1800 m., 1906, *Monetti* (Ost); Tapia, 1920, *Schreiter 27/2347* (G, BA); dept. Famailla, Villa Nougues, alt. 1000 m., 1922, *Venturi 1900* (G, US); 1927, *Venturi 5476* (G); Catamarca: Andalgalá, 1917, *Jörgensen 1581* (G, US, Mo, Ost); La Rioja: Yerba Buena, Cerro Famatina, 1928, *Castellanos 28/104* (G, BA); Córdoba: *Lossen 191* (G, FM, Mo, Bailey); Sierra Achala, *Hieronymus 349* (B, type); Puerto Alegre, Sierra Achala, 1877, *Hieronymus* (US); Sierra Chica, Cuesta del

Pan de Azucar, 1887, *Hieronymus* (S); Los Gigantes, 1890, *Kurtz 6927* (NY); La Falda, Sierra Chica, alt. 1000 m., 1917, *Osten 10580a* (Ost); 1918, *Osten 13457* (Ost, S); *13487* (Ost); Valle Hermoso, Sierra Chica, alt. 1000 m., 1917, *Osten 10581* (Ost); Rio Pintos, Sierra Chica, alt. 1000 m., 1918, *Osten 13491* (Ost).

Grisebach and later authors have frequently confused this form with dwarf specimens of *T. recurvata*, because of the close habital resemblance. However, there need be no difficulty in distinguishing the two if it is kept in mind that *T. recurvata* always has two bracts beneath the lowest flower, the floral bract and a scape-bract, while *T. capillaris* has but the floral bract.

d. Forma **virescens** (R. & P.), comb. nov. *Tillandsia virescens* R. & P. Fl. Peruv. iii. 43, t. 270, fig. b (1802); Spreng. Syst. ii. 23 (1825); R. & S. Syst. vii. 1200 (1830); Bak. Brom. 161 (1889); Mez in DC. Mon. Phan. ix. 879 (1896); Reiche, Pflanzenverbreit. Chile in Engl. & Drude, Veg. d. Erde, viii. 164 (1907); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 248 (1917); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930); Reiche & Looser, Geog. Bot. Chile, 257 (1934). *T. propinqua* Gay, Fl. Chil. vi. 15 (1853); E. Morr. in Belg. Hort. xxiii. 234 (1873); Phil. in An. Univ. Chile, lix. 323 (1881); Cat. Pl. Chil. 279 (1881); Bak. Journ. Bot. xvi. 237 (1878); xxv. 213 (1887); Brom. 160 (1889). *Diaphoranthema virescens* Beer, Brom. 154 (1857). *Tillandsia pusilla* Gill. ex Bak. in Journ. Bot. xvi. 237 (1878); xxv. 213 (1887); Brom. 160 (1889); Mez in DC. Mon. Phan. ix. 877 (1896); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 506 (1933). *T. lichenoides* Hieron. Ic. & Descript. Argent. 17 (1885). *T. Stolpi* Phil. in An. Univ. Chile, xci. 614 (1895). *T. Williamsii* Rusby, Bull. N. Y. Bot. Gard. vi. 489 (1910). *T. dependens* var. *Sanzini* Hicken in Physis, i. 388 (1914); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 244 (1917).

PERU: Huanuco: *Ruiz & Pavon* (type; Madrid (?), not yet discovered in any herbarium); Lima: Rio Blanco, alt. 3000–3500 m., 1929, *Killip & Smith 21640* (G, NY); Junin: Casacancha to Culnai, *Wilkes Expedition* (G, US); Tarma to Oroya, alt. 2700 m., 1903, *Weberbauer 2555* (S); Oroya, 1924, *F. L. Stevens 14* (US); Cuzco: near Cuzco, alt. 3300–3500 m., 1922, *F. L. Herrera 47* (Herrera!); alt. 3500 m., 1924, *F. L. Herrera 821* (US); 1916, *C. Watkins* (US); Arequipa: near Arequipa, alt. 2500 m., 1901, *R. S. Williams 2530* (NY, US, BM); Yura, alt. 2800 m., 1901, *R. S. Williams 2539* (NY, type of *T. Williamsii*); Puno: near Puno, alt. 3125 m., 1919, *Mrs. R. S. Shepard 48* (G); Indefinite: *Dombey 162 in part; C. Gay 546; Meyen; Stuebel* (Mez!). BOLIVIA: La Paz: near La Paz, alt. 3300 m., 1885, *Rusby 2164* (NY, FM, US); 1889, *Bang 123* (G, US, NY, Mo, BM); 3650–3800 m., 1906, *Buchtien 155 in part* (US); *805 in part* (S); 1910, *Buchtien* (Ost); *Buchtien 805 in part* (US, NY); *2556* (NY); 1911, *Buchtien* (NY); 1913, *Buchtien* (G, FM); 1918, *Buch-*

tien 107 (G); *381* (Mo, Pom, BM, S); 1930, *Jaffuel 585* (G); Ullama to Challapa, alt. 4000 m., 1921, *Asplund 6382* (US); Cochabamba: Cochabamba, alt. 3000 m., 1892, *Kuntze* (NY); Oruro: Pazña, alt. 4200 m., 1908, *Buchtien 1271* (US). ARGENTINA: Jujuy: La Rinconada, alt. 3800 m., 1901, *Claren 11343* (S); Tilcara, alt. 3400 m., 1927, *Venturi 7638* (G); Moreno, alt. 3500 m., 1901, *Fries 682a* (S); Abra de Tactul, alt. 4000 m., 1901, *Fries 689* (S); Los Andes: Susques, 1927, *Castellanos 27/773* (G, BA); Salta: Guachipas, 1873, *Lorentz & Hieronymus 1180* (S, B, type of *T. lichenoides;* phot. G); dept. Candelaria, Sierra de la Candelaria, alt. 1100 m., 1924, *Venturi 8666* (US); dept. San Carlos, Cerro de Cachi, alt. 2500 m., 1927, *Venturi 7302* (US); same, alt. 3000 m., *Venturi 7296* (US); Tucuman: 1933, *Burkart 5376* (G, SP); dept. Tafi, Peñas Azules, alt. 3800 m., 1933, *Parodi 10889* (G); Valle de Tafi, alt. 2000 m., 1918 and 1923, *Schreiter 805; 3287* (Ost); La Rioja: Cerro Famatina, Cienaga de Cosme, 1928, *Castellanos 28/101* (G, BA); Cerro Famatina, Guanchin, 1928, *Castellanos 28/103* (G, BA); Mendoza: *Gillies* (K, type of *T. pusilla;* phot. G); 1921, *Hosseus* (S); dept. Las Heras, alt. 2800 m., 1913, *Sanzin 56* (Ost, phot. G); 1916, *Sanzin 25/1868* (G, BA); Precord San Ignacio, alt. 1300 m., 1915, *Sanzin 567* (Ost). CHILE: Coquimbo: *Gay* (P, type of *T. propinqua;* phot. G); near Illapel, 1914, *Rose 19256* (US, NY); Aconcagua: Llayllay, 1832, *Bridges 534* (K, phot. G; BM); O'Higgins: dept. Victoria, Naltagua, 1888, *Stolp* (Chile, type of *T. Stolpi;* phot. G); Indefinite: *Cuming 167* (BM, K, phot. G); *Philippi 968* (P).

Sanzin 56, cited above, is probably the type collection of *T. dependens* var. *Sanzini*, but unfortunately there is no number cited in the type description.

e. Forma **Hieronymi** (Mez), comb. nov. *Tillandsia Hieronymi* Mez in DC. Mon. Phan. ix. 876 (1896); Kuntze, Rev. Gen. iii. 304 (1898); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 244 (1917); Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 503 (1933). *T. propinqua* Gay sensu Griseb. Symb. Argent. in Goett. Abh. xxiv. 334 (1879); Hieron. Ic. & Descript. Argent. t. 3, figs. 2–3 (1885); Bak. Brom. 160 (1889), in part. non Gay. *T. dependens* Hieron. ex Mez in DC. Mon. ix. 880 (1896); Hauman & Vanderveken, Phan. L'Arg. i., in An. Mus. Nac. Hist. Nat. B. A. xxix. 244 (1917); Harms in Engl. & Prantl, Nat. Pflanzenf. ed. 2, xv a. 122 (1930). Vars. *perusneoides* and *percordobensis* Mez, ibid. 881; Hauman & Vanderveken, ibid. Formae *perusneoides* and *percordobensis* Castellanos, Brom. Arg. iv., in An. Mus. Nac. Hist. Nat. B. A. xxxvii. 500 (1933).

BOLIVIA: La Paz: Palca to Illimani, alt. 3600–4300 m., 1906, *Hauthal* (S); Tarija: Tarija, alt. 2000 m., 1932, *Cardenas 212* (G). ARGENTINA: Jujuy: Quinta, near Laguna de la Brea, 1901, *Fries 34* (S); dept. San Pedro, Sierra Santa Barbara, alt. 750 m., 1929, *Venturi 9743 a* (G); Salta: dept. Candelaria, Sierra de la Candelaria, alt. 1000–1150 m., 1924, *Venturi 4079; 8668* (US); Tucuman: dept. Leales, Chañar Pozo, alt. 300 m., 1919, *Venturi 736* (G); Vipos, 1922, *Venturi 1228* (G, BA); dept. Trancas, Tapia, alt. 750 m., 1921, *Venturi 1364* (US); Catamarca: dept. Santa Maria, Portezuelo to Las Animas, alt. 3000 m., 1925, *Venturi 6890* (US); La Rioja: Cerro Famatina, Cienaga de Cosme, 1928 *Castellanos 28/102* (G, BA); Sierra Famatina, Guanchin, 1928, *Castellanos 28/105* (G, BA); Córdoba: 1891, *Kuntze* (NY); *Hieronymus 124* (B, type; FM, US, phot. G); *422* (Mez!); *870* (B); *Hieronymus & Niederlein; Kurtz 4398; 6667; Lorentz 124; 126 in part; 127 in part; 868; Lorentz & Hieronymus 527* (Mez!); *Kurtz 6597* (NY); Cuesta del Pan de Azucar, Sierra Chica, 1881, *Hieronymus* (NY); Sierra de Córdoba, *Hieronymus 352* (B, type of *T. dependens* var. *percordobensis;* phot. G); 1876, *422* (S); Cerro Champagni, near Rio Cobre, Sierra Achala, 1877, *Hieronymus 781* (B, type of *T. dependens* var. *perusneoides;* FM, US, phot. G); Dean Funes, 1916, *Sanzin 1159* (Ost); La Falda, Sierra Chica, alt. 1000 m., 1917–8, *Osten 10580-b* (Ost); *13460* (Ost, S); *13461* (Ost); *Los Paredones near Capilla del* Monte, Sierra Chica, alt. 1000 m., 1918, *Osten 13475* (Ost); Huerta Grande, Sierra Chica, alt. 1000 m., 1918, *Osten 13482* (Ost); Valle Hermoso, Sierra Chica, alt. 950 m., 1918, *Osten 13483; 13485* (Ost); Cajon de Rio Primero near San Antonio, Sierra Chica, alt. 900 m., 1918, *Osten 13490* (Ost); San Luis: Quebrada del Salado, near Bebida de las Vacas, 1882, *Galander* (S); Villa Mercedes, 1926, *Castellanos 25/2779* (G, BA); Merlo to Rincon, 1929, *Tepes 29/67* (G, BA).

It seems doubtful if the material which Mez described under *T. dependens* is really a hybrid with *T. usneoides* as he thought. To be sure the stem and leaves are somewhat more elongate than in other specimens of *T. capillaris*, but there is no tendency toward alternation of long and short internodes on the stem and consequent exposing of portions of the internodes such as one might expect in any hybrid involving *T. usneoides.*

40. **Tillandsia** (§ **Diaphoranthema**) **usneoides** L. Plant growing pendent from trees in branching strands up to 8 m. long: roots absent: stem sympodial, less than 1 mm. in diameter, internodes 3–6 cm. long with only the extreme base covered by the leaf-sheath, strongly curved, pseudo-axillary branches really a continuation of the main axis, very short and concealed by the basal leaf-sheath, bearing 2–3 leaves: leaves distichous, 25–50 mm. long, densely cinereous- or ferrugineous-lepidote; sheaths elliptic, involute, up to 8 mm. long; blades filiform, less than 1 mm. in diameter: scape practically none: inflorescence reduced to a single pseudo-terminal flower; floral bract ovate, apiculate or caudate, densely lepidote, shorter than the sepals: flower subsessile; sepals narrowly ovate, acute, up to 7 mm. long, thin, strongly nerved, glabrous, equally short-connate; petals narrow, acute or obtuse, 9–11 mm. long, pale green or blue; stamens deeply included, exceeding the pistil: capsule up to 25 mm. long, cylindric, abruptly short-beaked.—Always epiphytic; southeastern United States to central Argentina and Chile, but apparently very rare or absent in the Amazon Basin.—Sp. Pl. ed. 2, 411 (1762); Lam. Encycl. i. 619 (1785); Willd. Spec. ii. 15 (1799); R. & P. Fl. Peruv. iii. 43 (1802); Michx. Fl. Bor.-Am. i. 195 (1803); Poir. Encycl. vii. 672 (1806); Pursh, Fl. Sept.-Am. i. 217 (1814); Meyer, Fl. Esseq.

146 (1818); Nutt. Gen. i. 208 (1818); Ell. Bot. S. Car. & Ga. i. 379 (1821); LeC. in Ann. Lyc. Nat. Hist. N. Y. ii. 132 (1828); R. & S. Syst. vii. 1199 (1830); Gray, Man. ed. 2, 458 (1856); Beer, Brom. 151 (1857); E. Morr. in Belg. Hort. xxvii. 313, t. 17 (1877); Hook. f. in Bot. Mag. ciii. t. 6309 (1877); F. von Hoehnel in Dingler's Polytechn. Journ. n. 234. 407 (1879); Benth. & Hook. Gen. iii. 669 (1883); Hemsl. Biol. Centr.-Am. iii. 322 (1884); Wittm. in Engl. & Prantl, Nat. Pflanzenfam. ii. Abt. 4, 56, t. 27 (1888); Bak. Journ. Bot. xxv. 212 (1887); Brom. 159 (1889); Mez in Mart. Fl. Bras. iii. pt. 3, 613 (1894); Mez in DC. Mon. Phan. ix. 881 (1896); Britton & Brown, Ill. Fl. i. 374, t. 904 (1896); J. Huber, Bolet. Mus. Para. iii. 328 (1902); F. H. Billings, Bot. Gaz. xxxviii. 99 (1904); Pulle, Pl. Surinam, 92 (1906); Boldingh, Fl. Ned. W.-I. 144 (1913); Hassler, Cons. & Jard. Bot. Genève, xx. 336 (1919); J. Weese in Wiesner, Rohstoffe, n. 4. 649 (1927); Harms in Engl. & Prantl, Nat. Pflanzenfam. ed. 2, xv a. 122 (1930); Herter, Fl. Urug. 45 (1930); Standl. Field Mus. Pub. Bot. iii. 222 (1930); x. 129 (1931). *Camanbaya* Marcgrav. Bras. 46 (1658); Petiv. Gaz. t. 62, fig. 12 (1709). *Cuscuta, ramis arborum innascens Caroliniana, filamentis lanugine tectis* Pluken. Alm. 126 (1696) and Phytogr. t. 26, fig. 5 (1691); Moris. Hist. Oxon. iii. 615 (1715). *C. lendiginosa tenuissime cirrhis* Pluken. Alm. 126 (1696) and Phytogr. t. 26, fig. 6 (1691). *C. americana super arbores se dissidens* Ray, Hist. Pl. ii. 1904 (1693). *Viscum Caryophylloides tenuissimum, e ramulis arborum musci in modum dependens, foliis pruinae instar candicantibus, flore tripetalo, semine filamentoso* Sloane, Cat. 77 (1696); Ray Hist. Pl. Suppl. 406 (1704); Sloane, Hist. i. 191, t. 122, figs. 2–3 (1707). *Renealmia filiformis intorta* L. Hort. Cliff. 129 (1737); Gron. Virg. 36 (1739); Royen, Lugd.-Bat. 25 (1740); Barrère, Aequin. 99 (1741). *Fucus filum* Esper, Fuc. t. 20 (1800). *Rhizomorpha ochreata* Achar. Syn. 391 (1814). *Renealmia usneoides* L. Sp. Pl. 287 (1753). *Tillandsia trichoides* HBK. Nov. Gen. i. 290 (1816); R. & S. Syst. vii. 1200 (1830); Beer, Brom. 153 (1857). *T. filiformis* Lodd. Catal. ex R. & S. Syst. vii. 1229 (1830). ? *T. pendula* Hort. Lovan. ex R. & S. Syst. ibid. *Dendropogon usneoides* Raf. Fl. Tellur. iv. 25 (1838); Small, Fl. s. e. U. S. 245 (1903); Britton & Brown, Ill. Fl. ed. 2, i. 456, t. 1146 (1913); Britton & Wilson, Bot. P. Rico, v. 138 (1923). *Strepsia usneoides* Steud. Nomencl. ed. 2, ii. 645 (1841). *Tillandsia crinita* Willd. ex Beer, Brom. 152 (1857). *T. usneoides* formae *genuina, longissima, filiformis, major, ferruginea, crispa* André, Brom. Andr. 64 (1889). Forma *cretacea* Mez in Mart. Fl. Bras. iii. pt. 3, 615 (1894). Forma *robusta* E. Morr. ex Mez, ibid. Var. β. *filiformis* Mez

in DC. Mon. Phan. ix. 883 (1896); var. γ. *ferruginea* Mez, ibid; Castellanos, Physis, x. 89 (1930); var. δ. *longissima* Mez in DC. Mon. Phan. ix. 883 (1896); var. ε. *robusta* Mez, ibid.; var. ζ. *cretacea* Mez, ibid.—Spanish moss; Long moss; Black moss; Old man's beard; Barba española (Central America); Pashte (Honduras); Mexnuxib; Meexnuxib; Soscilchac (Yucatan); Guataca (Cuba); Barba de ucar (Porto Rico); Barba do velho; Barba de páo; Barba del monte (Brazil); Barba de monte; Barba de tala; Barba de palo; Barba de viejo (Uruguay); Barbon (Chile); Crin végétal (French); Baumhaar; Hangendes Moos (German).

UNITED STATES: Virginia: Northampton Co.: Eastville, *Canby* (Mo); Princess Anne Co.: Virginia Beach, *N. L. Britton* (NY); *Vail* (NY); Knott's Is., *Harper 10* (NY, FM); Norfolk Co.: Dismal Swamp, Lake Drummond, *Leonard & Killip 412* (FM); Norfolk, *Durand* (G); *E. G. Britton* (NY); North Carolina: Beaufort Co.: Leechville, *Wiegand & Manning 724* (G); Craven Co.: Lake Ellis, *Brown 110* (US); Havelock, *Fogg 5525* (G); Bladen Co.: *Ashe 2388* (NY); Elizabethtown, *Heller 14081* (FM); New Hanover Co.: Wrightsville, *Biltmore hb. 4701 a* (G, NY, Mo, BM); Forsyth Co.: Winston-Salem, *Schallert* (NY); Iredell Co.: Statesville, *Hyams* (Pom); South Carolina: Williamsburg Co.: Kingstree, *Wiegand & Manning 725* (G); Georgetown Co.: Santee Canal, *Ravenel* (S); Dorchester Co.: Summerville, *Taylor* (G); Charleston Co.: Edisto Is., *Murray 1299* (NY); Beaufort Co.: Bluffton, *Mellichamp* (US, Mo); Georgia: Richmond Co.: Augusta, *Olney & Metcalf 98* (G); McIntosh Co.: Darien, *Gilbert* (NY); *H. H. Smith 2140* (FM); Glynn Co.: Brunswick, *Chapman 472* (G); Charlton Co.: St. Marys River, *Small* (NY, FM); Sumter Co.: Flint River, *Harper 1048* (G, NY, Mo, BM); Dougherty Co.: Albany, *Gillespie 10000* (Bailey); Thomas Co.: Thomasville, *Clarke* (NY); Florida: Duval Co.: *Fredholm 103* (Pom); *5231* (G); Jacksonville, *Churchill* (G); *Curtiss 2850* (G, NY, BM); *4142* (NY); *4673* (G, NY); *Keeler* (NY); St. Nicholas, *Lighthipe 58* (NY); Alachua Co.: Gainesville, *Garber* (G); *Knight 7883* (NY); Volusia Co.: New Smyrna, *Deam 1605* (NY); Enterprise, *Faxon* (G); Ormond, *Gilbert* (G); Lake Co.: Eustis, *Nash 464* (G, NY); *1932* (NY); Orange Co.: Winter Park, *Ensminger* (G); *Lewton* (NY); Brevard Co.: Cape Canaveral, *Burgess 689* (NY); Pinellas Co.: Tarpon Springs, *Wilson* (NY); Hillsborough Co.: Tampa, *Merrill* (NY); Palm Beach Co.: Juno, *Randolph & Small 61* (G); Lee Co.: Ft. Myers, *Hitchcock 348* (G, NY); *Standley 157* (G, NY); Dade Co.: Miami, *Moldenke 538* (NY, S); Elliott's Key, *Small & Nash* (NY); Cutler, *Small & Carter* (NY); Miami R., *Small 4537* (NY); Leon Co.: Tallahassee, *Rugel 380* (NY, BM); Alabama: Elmore Co.: Tallassee, *Harper 80* (G, NY, Mo, Bailey); Montgomery Co.: Montgomery, *McCarthy* (G); Mobile Co.: Mobile, *Dewey* (G); *Graves 863* (Mo); Mississippi: Hinds Co.: Clinton, *Smart* (G); Adams Co.: Natchez, *Shimek* (FM, Mo); Jackson Co.: Ocean Springs, *Pollard 1080* (G, NY, FM, Mo, Pom); Harrison Co.: Biloxi, *Baker* (NY); *Tracy* (NY, FM, BM); Hancock Co.: Bay St. Louis, *Munz 1369* (Pom); Louisiana: St. Tammany Co.: Mandeville, *Pennell 4202* (NY); Plaquemines Co.: Myrtle Grove, *Benke 5523* (G, FM); Rapides Co.: Alexandria, *Ball 504* (G, NY, FM, Mo, BM); St. Landry Co.: Melville, *Bush 251* (NY); East Baton Rouge Co.: *Joor* (FM); St. Martin Co.: St. Martinville, *Langlois* (Bailey); Orleans Co.: New Orleans, *Benke 3182* (FM); Texas: Walker Co.: *Dixon 607* (FM, Pom); Dido, *Dixon 185* (FM); Huntsville, *Bailey* (Bailey); Montgomery Co.: Willis, *Dixon 282* (FM); Harris Co.: Houston, *Kuntze 23819* (NY); Brazos Co.: College Station, *Kellogg* (Mo);

Travis Co.: Austin, *Underwood* (NY); Hays Co.: San Marcos, *Trelease* (Mo); Comal Co.: New Braunfels, *Lindheimer 1202; 1203* (G, NY, FM, Mo, BM); Kendall Co.: *Reverchon 4036* (G, NY, Mo); Bexar Co.: San Antonio, *Bell* (NY); *Clemens 145* (Mo, Pom, Bailey); *Jermy 198* (G); Brazoria Co.: Columbia, *Bush 211* (NY, Mo); Brazoria, *Stewart* (G); Maverick Co.: Eagle Pass, *Plank* (NY); Nueces Co.: Corpus Christi, *Ravenel 171* (NY); Cameron Co.: Brownsville, *Ferris & Duncan 3176* (NY, Mo, Bailey). MEXICO: Tamaulipas: Tampico, *Lachen 96* (BM); *Palmer 183* (G, NY, FM, Mo, BM); *Mercier* (S); Gómez Fárias, *Palmer 359* (G, NY, Mo, FM); Jaumave to Victoria, *Rozynski 252* (FM); Nuevo Leon: near Pueblo Galeana, *Mueller 326* (G); Baja California: *Palmer* (Mo); Sinaloa: Mazatlan, *Lamb 378* (NY, Bo); *379* (G, DH); *Ortega 6841* (FM); Durango: Durango, *Palmer 124* (G, NY, FM, Mo, UCal, BM, Bo, S); San Luis Potosi: Los Canos, *Palmer 229* (G, NY, FM, Mo); Vera Cruz: Maltrata, *Kerber 262* (BM); Vera Cruz, *Houston* (Cam); Orizaba, *Mueller 347* (NY); Nayarit: Pedro Paulo, *Rose 2004* (G); Michoacan: Chapultepec, *Berlandier 46 a* (BM); *Brandegee* (UCal); *Gregg* (G, Mo); *Bourgeau 95* (G, S); Mexico: Amecameca, *Fröderström & Hultén 1206* (S); Valley of Mexico, *Schmitz* (BM); *Schaffner* (BM); Federal District: Mexico City, *Tenfer* (NY); Tlaxcala: Santa Ana, *Arsène 7* (Mo); Puebla: San Luis Tultitlanapa, *Purpus 3395* (G, NY, FM, Mo, BM, S); Cerra de Pinas, *Russell & Souviron 238* (US); Guerrero: Acapulco, *Palmer 537* (G, NY, FM, Mo); Chiapas: San Vicente, *Nelson 3504* (G); Yucatan: Silam, *Gaumer 663* (G, NY, FM, BM, S). GUATEMALA: Peten: Lake Yaxha, *Lundell 2210* (G); Baja Verapaz: Sierra de las Minas, *Kellerman 6282* (FM); Santa Rosa, *Tuerckheim 325* (G); *II 2333* (NY); Guatemala: Guatemala, *Hayes* (G); Santa Rosa: Santa Rosa, *Heyde & Lux 4633* (G). HONDURAS: Atlántida: Tela, *Standley 56702* (FM); Comayagua: Siguatepeque, *Standley 56070* (G, FM); Olancho: Salama, *Weaver 2* (NY). NICARAGUA: *Wright* (Mo). COSTA RICA: Cartago: Turrialba, *Pittier & Tonduz 8246* (Bo); *Polakowsky 498* (BM); Cartago, *Polakowsky 99* (BM). BAHAMAS: 1730, *Dale* (BM); New Providence Is., *Britton & Brace 238* (NY, FM); Cat Is., *Britton & Millspaugh 5965* (NY, FM); Inagua Is., *Nash & Taylor 1179* (NY, FM). CUBA: Isla de Pinos: Rio Nuevas, *Jennings 292* (BM); Sierra de Casas, *Ekman 12567* (S); McKinley, *Jennings 301* (NY); Pinar del Rio: Bañas San Vicente, *Britton & Gager 7380* (NY); Galafre, *Britton & Cowell 9831* (NY); Los Palacios, *Shafer 11817* (NY, Mo); Sumidero, *Shafer 13818* (NY, FM); Sierra de Anafe, *Wilson 11442* (NY); Havana: Loma Esperon, *Ekman 672* (S); Sierra de Anafe, *Ekman 1123* (G, Mo, S); Rincon, *Wilson 1059* (G, NY, FM); Matanzas: Matanzas, *Britton & Shafer 238* (NY); Santa Clara: Cieneguita, *Combs 343* (G, NY, FM, Mo); Camaguey: La Gloria, *Shafer 105* (NY, FM); Cayo Guajaba, *Shafer 723* (NY, FM); Oriente: *Wright* (G); Cabo Cruz, south of Niquero, *Ekman 16187* (S); Rio Rioja, *Ekman 4884* (Mo, FM, BM, S); Woodfred, *Ekman 15577* (G, S); Santiago, *Pollard & Palmer 275* (G, NY, FM, Mo); *Taylor 110* (NY); Farallon de La Perla, *Shafer 8778* (NY). JAMAICA: 1687–90, *Sloane* (BM, TYPE; phot. G); *Swartz* (S); Bridgehill, *Bot. Dept. Jamaica* (BM). HAITI: Anse Galette, Gonaive Is., *Leonard 3048* (NY); Gros Morne, dept. L'Artibonite, *Leonard 10018* (US); La Vallée, Tortue Is., *Leonard 15323* (US); Port Margot, *Nash 374* (NY); Marmelade, *Nash & Taylor 1239* (NY). SAN DOMINGO: Azua, *Rose, Fitch & Russell 3821* (NY); Constanza, *Tuerckheim 3062* (NY, BM); Moncion, Monte Cristi, *Valeur 262* (NY, FM, Mo, S); *788* (US). PORTO RICO: Coamo Springs, *Britton & Cowell 1330* (NY, FM); Ponce to Coamo, *Heller 513* (NY, FM); Mayaguez, *Hunn* (Bailey); Cabo Rojo, *Sintenis 569* (G, NY, S); Aguirre, *Underwood & Griggs 365* (NY). LESSER ANTILLES: St. Croix: *Ricksecker 267* (G, NY, FM, Mo); St. Martin: *Boldingh 3416* (NY); Guadeloupe: *Duss 3322* (NY); Martinique: *Duss 993* (NY);

Forsström (S); St. Vincent: *H. H. & G. W. Smith 1429* (NY); Trinidad: *Fendler 813* (BM); *R. Bot. Gard. Trin. 822.*(Trin.); *Sieber 345* (Mo). SURINAM: Paramaribo *Samuels 45* (G, NY). BRITISH GUIANA: *Schomburgk 159* (BM); Berbice: Canje Creek, *Bartlett* (Jenman). VENEZUELA: Sucre: Cristobal Colon, *Broadway 50* (G, NY); Managas: Caripe, *Humboldt & Bonpland 347* (B, P, type of *T. trichoides* and *T. crinita;* phot. G); Delta Amacuro: Corisal, *Bond, Gillin & Brown 199* (G); Distrito Federal: Caracas, *Bailey 574* (G, Bailey); Aragua: Colonia Tovar, *Fendler 1535* (G, NY, Mo, S); Merida: Tabay, *Gehriger 431* (NY, FM); Timotes, *Vogl 1043* (Mun). COLOMBIA: Bolivar: Cartagena, *Triana 534* (BM); Norte de Santander: Toledo, *Killip & Smith 20121* (G, NY, FM); Santander: Bucamaranga, *Killip & Smith 16348* (G, NY, FM, S); Cundinamarca: Fusagasuga, *André 1860* (G, NY); Pandi, *Pennell 2836* (NY); El Valle: La Paila, *Holton 155* (NY). ECUADOR: *Spruce 5435* (G, BM); Azuay: Cuenca, *Rose 22943* (G, NY); Oro: Machala, *Barclay 515* (BM); Loja: El Tambo to La Toma, *Hitchcock 21325* (G, NY). PERU: *Ruiz & Pavon* (BM); Piura: Cerro Prieto, *Haught F-124* (FM); Huanuco: Huanuco, *Macbride & Featherstone 2378* (G, FM, S); Lima: Matucana, *Rose 18671* (NY); Cuzco: Valle del Paucartambo, *Herrera 3378* (G, FM); Cuzco, *Herrera 820* (FM). BOLIVIA: La Paz: Sorata, *Mandon 1182* (G); La Paz, *Bang 107* (G, NY, FM, Mo, BM); *Buchtien 155 in part* (G); *599* (NY, FM, Mo, Pom, S); *Jaffuel 583* (G); Illimani, *Buchtien* (BM); Chuquisaca: prov. Cinti, Huarinota, Quebrada Honda, alt. 3200 m., *Hammarlund 375* (S). BRAZIL: Ceará: *Allemão CLXXI in part* (MN Rio); *Allemão & Cysneiros 1524* (MN Rio); Pernambuco: Jaqueira, *Ridley, Lea & Ramage* (BM); Bahia: *Glocker 198* (S, BM); Minas Geraes: Caldas, *Regnell III 1251* (S, FM, MN Rio); Lagoa Santa, *Hoehne 6353* (MN Rio); Turvo, *Hoehne & Gehrt 17574* (G, SP); Rio de Janeiro: Nictheroy, *Smith & Brade 2328* (G); Federal District: Rio de Janeiro, *Andersson* (S); *Forsett 93* (S); *Mosén 2622* (S); *Widgren* (S); São Paulo: Moóca, *Brade 6310* (S); *6311* (G, S, SP); Butantan, *Hoehne 12* (G, SP); Santos, *Luederwalt & Fonseca 12383* (G, SP); Piracicaba, *Puttemans 12382* (G, SP); Piquete, *Robert* (BM); Ytú, *Russell 17975* (G, SP); Cubãtao, *Smith 2041* (G, S, FM); São Paulo, *Smith & Kuhlmann 1811* (G); Paraná: Restinga Secca, *Dusén 3130* (S, MN Rio); Serrinha, *Dusén 17673* (G, S, BM); Tibagy, *Reiss 16* (G); Santa Catharina: *Macrae* (BM); Rio Grande do Sul: Porto Alegre, *Lindman A 469* (S). PARAGUAY: *Jörgensen 4483* (Mo, DH, S); Pilcomayo River, *Morong 886* (NY, FM, Mo, BM). URUGUAY: Artigas: Arapey, *Osten 3287* (Ost); Cerro Largo: Palleros, *Herter* (Ost); Treinta y Tres: Tacuari, *Herter 94037* (G, Mo); Rio Negro: *André K 325* (G, NY, FM); Soriano: Mercedes, *Osten 3121* (Ost). ARGENTINA: Jujuy: Sierra de Santa Barbara, 1901, *Fries 413* (S); Tucuman: La Cienaga, *Lorentz 798* (G, BM, SP); Córdoba: *Lossen 428* (G, FM, Mo, Bailey); Sierra Grande, *Hieronymus* (FM); Sierra Achala, *Hieronymus* (NY); Los Gigantes, *Kurtz 6928* (NY); Buenos Aires: Barca Grande, Delta del Paraná, *Cabrera 1635* (G, SP). CHILE: Aconcagua: Quillota, *Bertero 1359* (G); Zapallar, *Behn* (FM); Valparaiso, *Dusén* (S); *King* (BM); Cerro Campana, *Looser 581* (G); Palos Quemados, *Looser 2760* (G); Quilpue, *Philippi & Borchers* (BM); Biobio: Santo Barbaro, *Reed* (BM); Rio Duqueco, *Reed* (G); Cautin: Temuco, *Claude-Joseph 1173* (US).

Considering its wide range, *T. usneoides* varies remarkably little and then without any discernible relation to its distribution. If the forms and varieties so far proposed are worth keeping then there is practically no limit to those that can and logically should be made. Consequently the species is considered here without any subdivision whatever.

Since no material of this species can be found in either the Linnean or Clayton collections, the type, like that of *T. recurvata*, must rest on Sloane's material.

Prof. Harms informs me that there is no specimen labelled *Tillandsia crinita* at Berlin-Dahlem, but that the specimen labelled *T. trichoides* in Willdenow's herbarium is the one that Beer described as *T. crinita*.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. GUZMANIA HITCHCOCKIANA L. B. Smith (*Hitchcock 20436*), branch of inflorescence × ½.
2. HECHTIA MEZIANA L. B. Smith (*Purpus 10276*), scape and lowest branch of inflorescence × ½.
3. Same, longitudinal section of flower × 2.
4. HOHENBERGIA INERMIS Mez (*Britton 1468*), petal and stamen × 5.
5. HOHENBERGIA CAYMANENSIS Britton (*Rothrock 495*), spike from near apex of inflorescence × ½.
6. Same, sepal × 3.
7. HOHENBERGIA NEGRILENSIS Britton (*Britton & Hollick 2023*), spike × ½.
8. Same, floral bract × 2.
9. HOHENBERGIA STELLATA Schult. f. (*Martius*), flower × 1.
10. MEZOBROMELIA BICOLOR L. B. Smith (*Killip 11396*), inflorescence × ½.
11. Same, corolla × 2.
12. CANISTRUM PERPLEXUM L. B. Smith (*Hoehne 31550*), inflorescence × ½.
13. Same, expanded sepal × 1.
14. Same, petal and stamens × 2.
15. Same, diagrammatical cross-section of petal and filaments × 10.
16. PUYA LASIOPODA L. B. Smith (*Rusby 2232*), floral bract and flower × ½.
17. Same, expanded sepal × 1.
18. PITCAIRNIA KNIPHOFIOIDES L. B. Smith (*Lehmann 3310*), inflorescence × ½.

PLATE II.

Fig. 1. PUYA SANCTAE-CRUCIS (Bak.) L. B. Smith (*Castelnau*), floral bract and flower × 1.
2. TILLANDSIA LEPIDOSEPALA L. B. Smith (*Pringle 5323*), habit × ½.
3. Same, sepal × 1.
4. TILLANDSIA CAULESCENS Brongn. (*Gay 1186*), habit × ¼.
5. TILLANDSIA ARGENTINA C. H. Wright (*Venturi 2494*), habit × ½.
6. Same (*Venturi 9978*), sepal × 1.
7. Same, petal and stamens × 2.
8. TILLANDSIA INCARNATA HBK. (*Humboldt & Bonpland*), habit × ¼.
9. Same (*Killip & Smith 19767*), posterior sepals × 1.
10. Same (*Rimbach 121*), petal and stamens × 2.
11. TILLANDSIA FRIESII Mez (*Fries 828*), habit × ½.

Plate III.

Fig. 1. Tillandsia cauligera Mez (*Weberbauer 4050*), habit × ¼.
2. Tillandsia arhiza Mez (*Balansa 4746*), habit × ¼.
3. Same (*Balansa 4747*), inflorescence × ½.
4. Tillandsia Werdermannii Harms (*Werdermann 717*), inflorescence and upper part of scape × ½.
5. Tillandsia Cardenasii L. B. Smith (*Cardenas 491*), habit × ½.
6. Same, expanded sepal × 1.
7. Tillandsia Ehrenbergiana Kl. (*Ehrenberg 860*), habit × ½.
8. Same, expanded sepal × 1.
9. Tillandsia Schiedeana Steud. (*Lundell 2517*), scape and inflorescence of small specimen × ½.

Plate IV.

Fig. 1. Tillandsia Funckiana Bak. (*Jahn 1088*), short branch with 2 flowers × ½.
2. Tillandsia erecta Bak. (*Gillies*), habit × ½.
3. Tillandsia caerulea HBK. (*Humboldt & Bonpland*), upper scape and inflorescence × ½.
4. Same (*Hitchcock 21334*), petal × 1.
5. Tillandsia bryoides Griseb. (*Aurelius 23*), habit × ½.
6. Same, leaf × 2.
7. Same (*Osten 5107*), inflorescence × 2.
8. Tillandsia aizoides Mez (*Osten 13471*), leaf × 2.
9. Same (*Hieronymus & Niederlein 850*), inflorescence × 2.
10. Tillandsia Gilliesii Bak. (*Gillies*), habit × ½.
11. Same (*Castellanos 27/2880*), leaf × ½.
12. Same, cross-section of leaf-blade × 2.
13. Tillandsia myosura Griseb. (*Venturi 8096*), scape and inflorescence × ½.
14. Same (*Schreiter 27/2336*), leaf × ½.
15. Same, cross-section of leaf-blade × 2.
16. Tillandsia angulosa Mez (*Hieronymus & Niederlein 851*), habit × 1.
17. Tillandsia Landbeckii Phil. (*Landbeck*), inflorescence and upper scape × 1.
18. Tillandsia andicola Gill. (*Schreiter 1136*), habit × ½.
19. Tillandsia rectangula Bak. (*Castellanos 25/624*), end of stem with inflorescence × ½.
20. Tillandsia retorta Griseb. (*Venturi 1029*), habit × ½.
21. Tillandsia crocata (E. Morr.) Bak. (*Dusén 9238*), habit × ½.
22. Same (*Tweedie 427*), inflorescence and upper scape × ½.

Plate I.

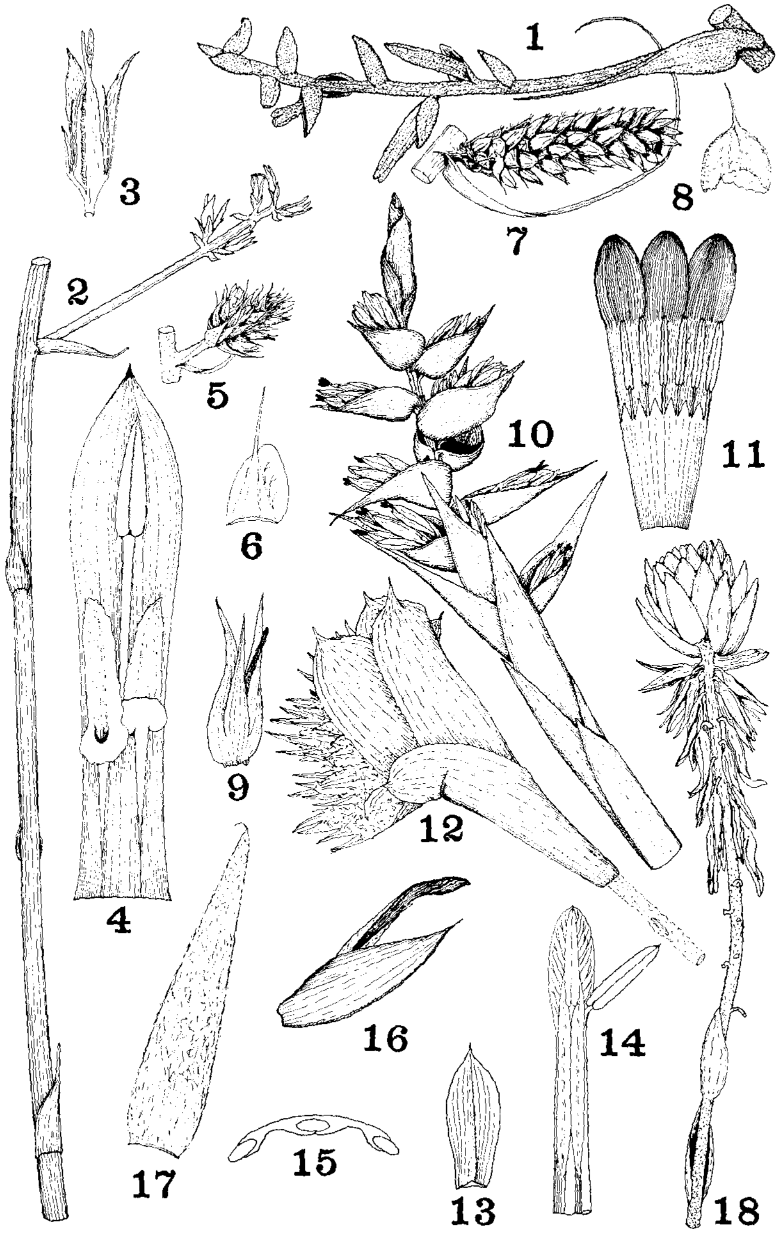

Fig. 1, Guzmania Hitchcockiana L. B. Sm.; 2–3, Hechtia Meziana L. B. Sm.; 4, Hohenbergia inermis Mez; 5–6, H. caymanensis Britton; 7–8, H. negrilensis Britton; 9, H. stellata Schult. f.; 10–11, Mezobromelia bicolor L. B. Sm.; 12–15, Canistrum perplexum L. B. Sm.; 16–17, Puya lasiopoda L. B. Sm.; 18, Pitcairnia kniphofioides L. B. Sm.

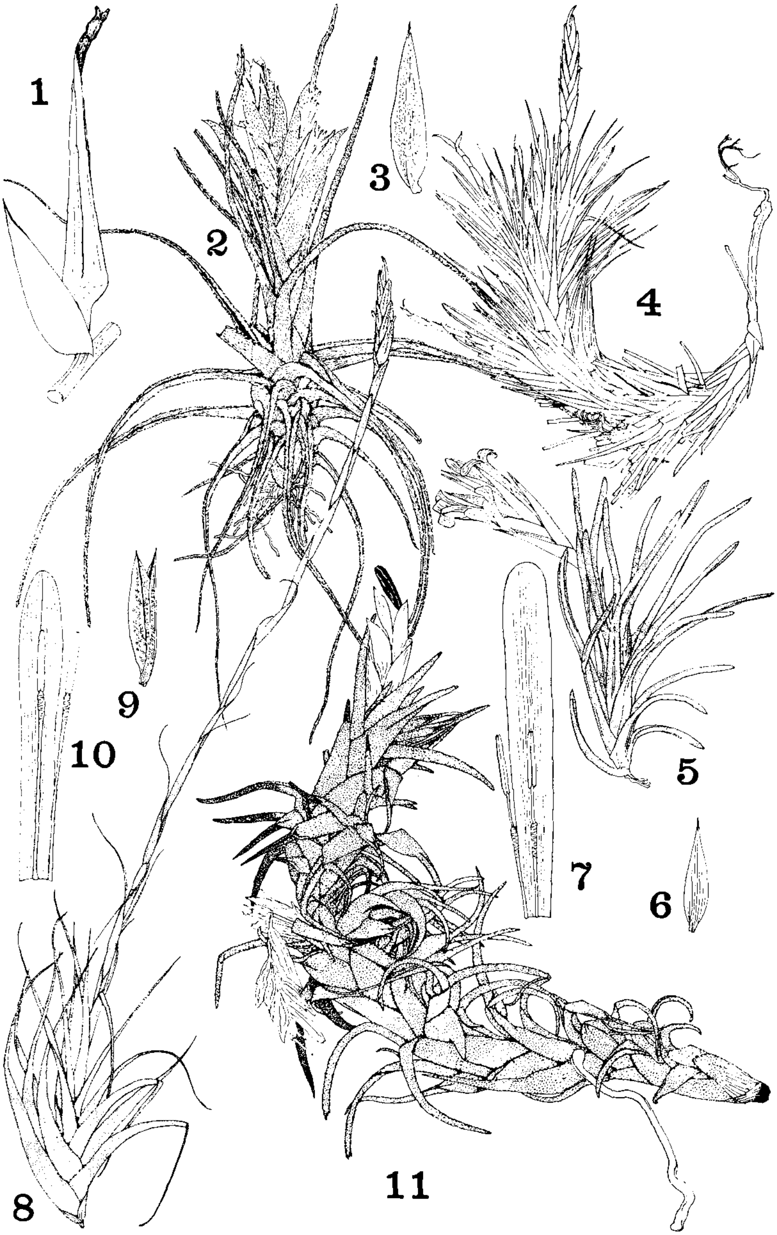

Fig. 1, Puya sanctae-crucis (Bak.) L. B. Sm.; 2–3, Tillandsia lepidosepala L. B. Sm.; 4, T. caulescens Brongn.; 5–7, T. argentina C. H. Wright; 8–10, T. incarnata HBK.; 11, T. Friesii Mez.

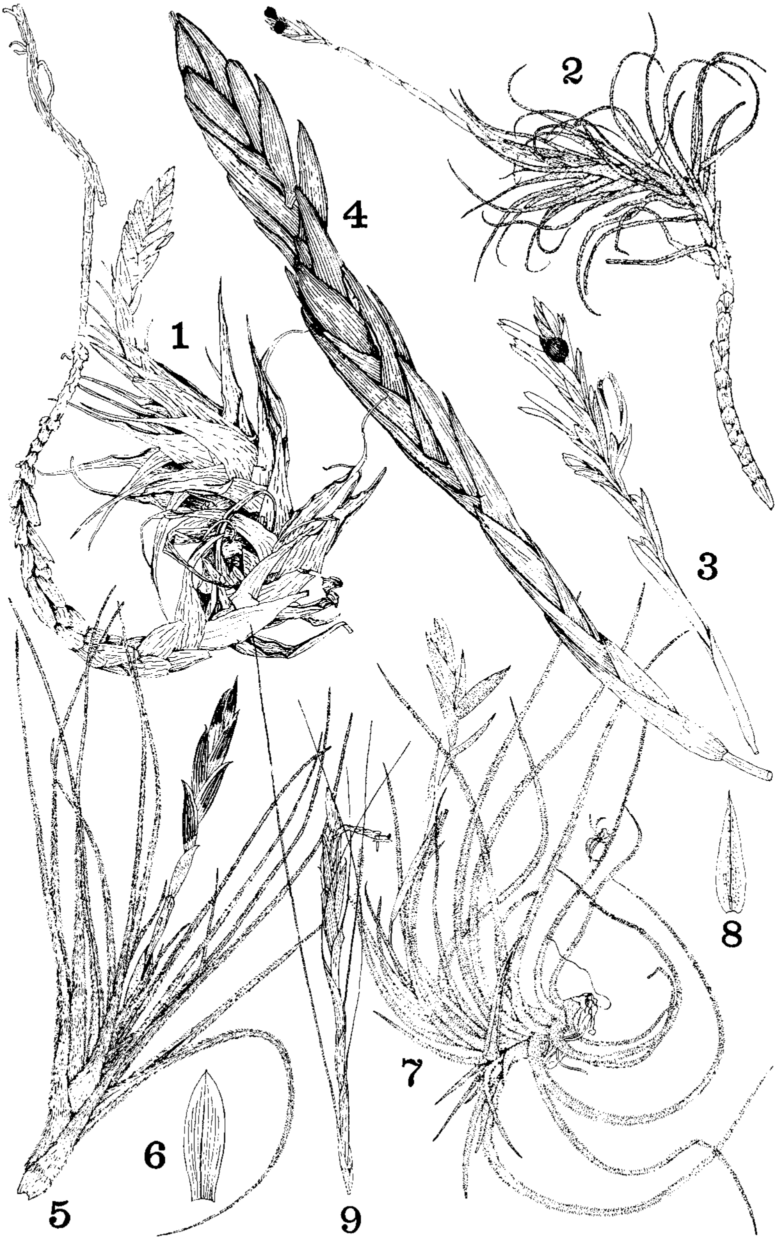

Fig. 1, Tillandsia cauligera Mez; 2–3, T. arhiza Mez; 4, T. Werdermannii Harms; 5–6, T. Cardenasii L. B. Sm.; 7–8, T. Ehrenbergiana Kl.; 9, T. Schiedeana Steud.

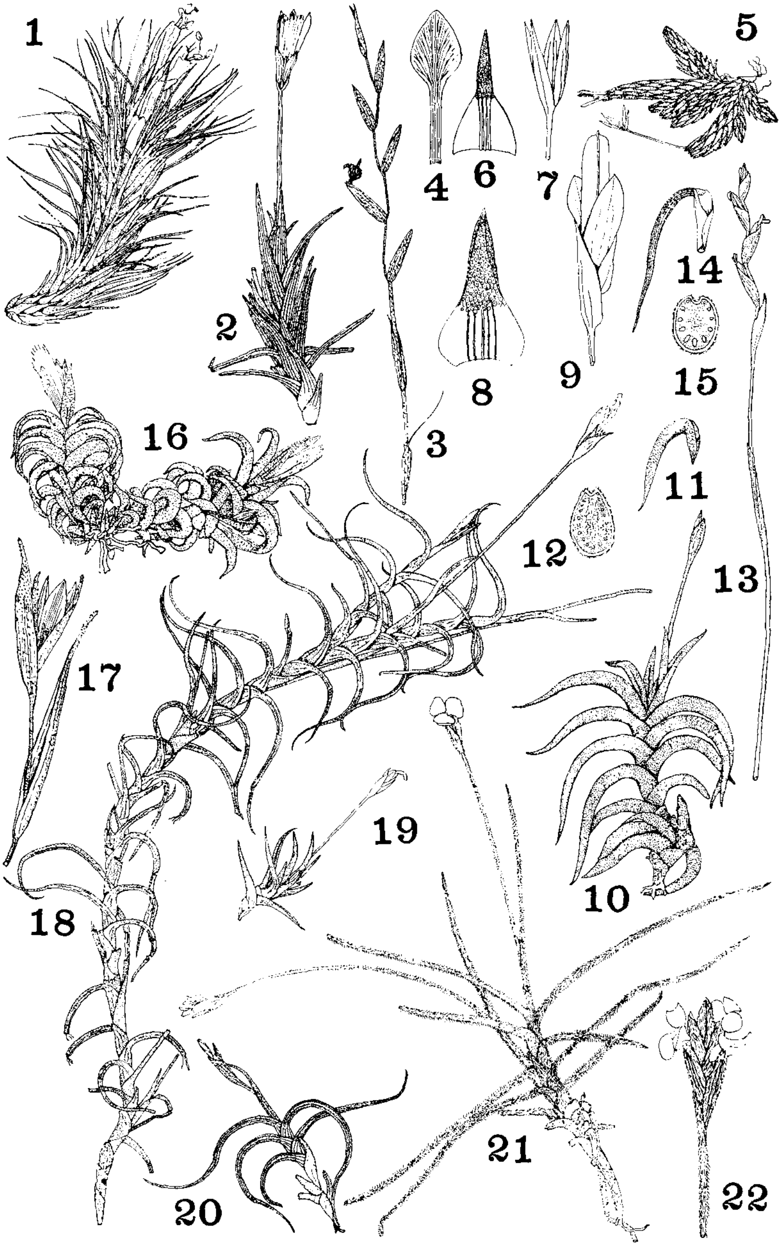
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Fig. 1, Tillandsia Funckiana Bak.; 2, T. erecta Bak.; 3–4, T. caerulea HBK.; 5–7, T. bryoides Griseb.; 8–9, T. aizoides Mez; 10–12, T. Gilliesii Bak.; 13–15, T. myosura Griseb.; 16, T. angulosa Mez; 17, T. Landbeckii Phil.; 18, T. andicola Gill.; 19, T. rectangula Bak.; 20, T. retorta Griseb.; 21–22, T. crocata (E. Morr.) Bak.

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70—6

Proceedings of the American Academy of Arts and Sciences

Vol. 70, No. 6—December, 1935

An Ancient Chinese Alchemical Classic

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The Fourth and Sixteenth Chapters of Pao-p'u-tzŭ
Translated from the Chinese

By Lu-Ch'iang Wu

with an Introduction, etc.

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With 8 Figures

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Received August 6, 1935. Presented March 13, 1935.

INTRODUCTION

Pao-p'u-tzŭ, of which two of the most interesting chapters are now made available for the first time in a European language, is probably the widest known and highest regarded of the ancient Chinese treatises on alchemy. It has been preserved for us as part of the Taoist canon. It shows us the art matured by five or six centuries of practice, having its traditional heroes and an extensive literature, its technique and philosophy now clearly fixed, its objectives and pretentions established. This art the author examines in a hard-headed manner and expounds in language which is remarkably free from subterfuge.

Ko Hung (about 281–361 A.D.) was one of the outstanding scholars of the *Chin* dynasty, a Taoist philosopher and writer on medical, alchemical, literary, and historical subjects. He defended the Taoist doctrines at a time when they had not yet gained wide currency, and propagated them before Taoism had assumed a churchly organization. He believed in magic but probably no more so than his contemporaries. He was credulous but had the admirable credulity of an inquiring experimentalist who was well aware of the powers and possibilities of nature.

Alchemy arose in China during the third or fourth century B.C., apparently a spontaneous and indigenous growth out of Taoist mysticism.[1] The *Tao* or Way was to be attained by inaction. Those who sought for it, despairing of accomplishing a perfect control of the self, tried physical means of attaining it, deep breathing, abstinence, and the use of medicines of immortality. Those who had attained the *Tao* became *Hsien,* supernatural immortals having eternal youth and other marvelous powers, capable of passing through fire and water without harm, of traversing great distances in a moment of time, of changing their forms at will, etc. On attaining complete inaction, they were capable of all or any action however extraordinary—in accordance with the usual dialectic of mysticism.

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[1] For a fuller account of the origins and growth of Chinese alchemy and of the alchemists who practiced the art before *Ko Hung* see *Isis, 18*, 210–230 (1932), the Introduction to *Wu's* translation of the *Ts'an T'ung Ch'i* of *Wei Po-yang*.

The notion of *Hsien* appears to have arisen naturally out of a discussion and elaboration of the philosophy of *Lao-tzŭ.* It seems to have been the central idea of Chinese alchemy. Recent evidence, in particular that which is supplied by the present translation and by *Wu's* translation of the *Ts'an T'ung Ch'i,* tends to support the early opinion of Edkins[2] who believed that European alchemy was derived from that of China, that Chinese alchemy reached the Arabs, and thence Europe, through Persia with which country the Chinese had intercourse both before and after its conquest by the Mohammedans. There is no evidence that alchemy existed in Europe, or in Byzantium or Alexandria, before the eighth century or thereabouts when the Arabs began to practice it—and the opinion of Martin[3] and more recently that of Johnson[4] that Chinese alchemy came to Europe through Byzantium and Alexandria cannot be accepted. Indeed the present translation supplies new evidence of the fundamental dissimilarity between the aims of the Chinese alchemists who sought to make real gold and silver artificially and those of the Alexandrian and Byzantine chemists who strove to tincture base metals to the appearance of the noble ones. The present translation also gives a very full picture of the notion of *Hsien,* which notion must surely have been attached to Chinese alchemy when it came to the Arabs. But the notion does not appear in European alchemy at all. Perhaps it failed to appeal to the European alchemists whose Mohammedanism and Christianity promised them an immortality anyway. They sought for an elixir of long life but not for a medicine of immortality, for the best of natural human powers but not for supernatural ones.

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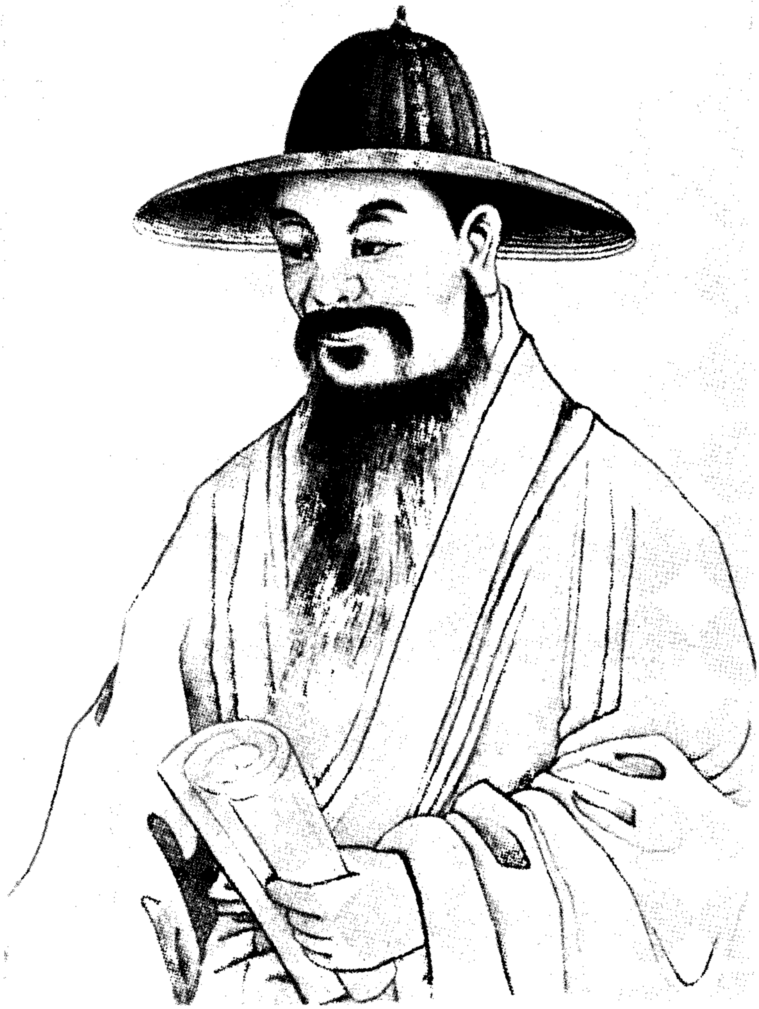
[2] Rev. Joseph Edkins, *Trans. China Branch Roy. Asiatic Soc.,* Hong Kong, 1855, part 5, pp. 83–99.

[3] W. A. P. Martin, *The Lure of Cathay or the Intellect of China,* New York, Chicago, and Toronto, 1901. *Chapter 3, Alchemy in China, the Source of Chemistry,* pp. 44–71.

[4] Obed S. Johnson, *A Study of Chinese Alchemy,* Shanghai, 1928.



Ko Hung.

The notion however seems to have survived in Arab lore. The marvelous powers of the *Hsien* are so like those of the *jinni* of the Arabian Nights that one wonders whether the Arabic work, *jinn*, may not be derived from the Chinese *Hsien*.

Ko Hung was a voluminous writer. His most important work, the pseudonymous *Pao-p'u-tzŭ*,[5] dates from about 317–332 A.D., and consists of seventy chapters or books. The text occupies six volumes or fascicles of a recent edition of the Collected Taoist Classics, and is divided into two parts, each occupying three volumes, the "Outer Chapters," *Wai-p'ien*, in fifty books, which deal with matters of politics and government from the Confucianist point of view, and the "Inner Chapters," *Nei-p'ien*, in twenty books, which treat of the immortals, alchemy, charms, exorcisms, etc. *Ko Hung* also wrote, evidently somewhat later, the *Shen Hsien Chuan* (Lives of the Immortals), ten books, which describes the lives of eighty-four *Hsien*. He wrote a large collection of medical recipes, *Chin Kwei Yao Fang*, one hundred books; literary works, legends, funeral orations, poems, etc., one hundred books; fragments relating to his official business, thirty books; and treatises on the classics, historians, and philosophers, three hundred and ten books. The Taoist canon also contains a number of shorter tracts on hygiene, medicine, alchemy, and magic which are ascribed to him, some of them wrongly as Forke[6] believes. The history of the *Chin* dynasty, which contains his biography, praises his extraordinary learning which was without equal. His writings are deep and very critical, and richer in content than the historical writings of *Ssu-ma Ch'ien* and *Pan Ku*.

"Nowhere in *Pao-p'u-tzŭ's* book," says Waley,[7] "do we find the hierophantic tone that pervades most writings on alchemy both in the East and in the West. He uses a certain number of secret terms. . . . But his attitude is always that of a solidly educated layman examining claims which a narrow-minded orthodoxy had dismissed with contempt. He condemns those who are unwilling to take seriously either 'books that do not proceed from the school of the Duke of *Chou* or facts that Confucius has not tested.'"

---

[5] This name has been translated *Old Sober-Sides*, but Dr. *Wu* considers that it has no satirical intent and would better be translated *Solemn-Seeming Philosopher*. The gentle smile in the portrait which is reproduced herewith perhaps agrees with its real intent.

[6] Alfred Forke, *Arch. f. Geschichte d. Philosophie, 41*, 115–127 (1932).

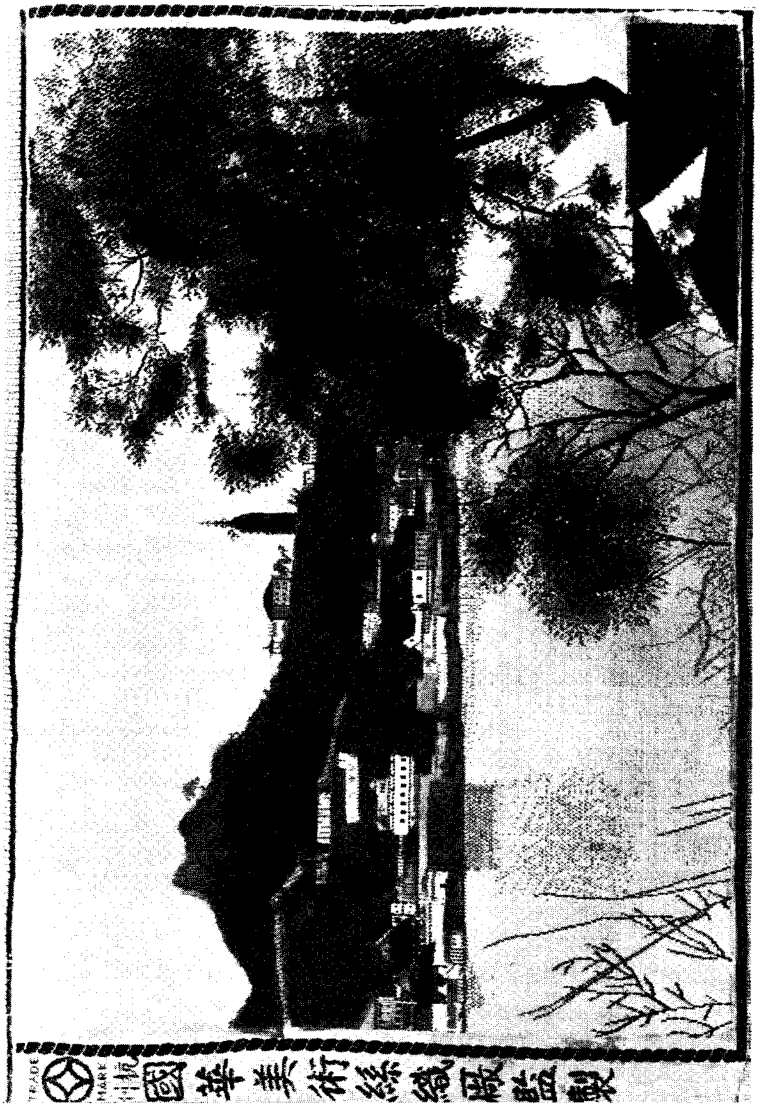
[7] A. Waley, *Bulletin of the School of Oriental Studies, London Institution*, Vol. VI, Part 1, 24 pp. (1930).

Ko Hung was born at *Chiang-ning-fu* in *Kiangsu*. It is reported that he showed an extraordinary fondness for learning while still a boy but that his family was poor and he was obliged to chop wood in order to earn money for the purchase of writing materials. At some time after 326 A.D., he asked the Emperor *Yüan-ti* to send him to *Kou-lou* because cinnabar, which he needed for his experiments, could be obtained there from Cochin-China. He set out on the journey but lingered in the neighborhood of Canton where he lived in the *Lo Fu* mountain studying and writing, and where he finally died. The account of *Ko Hung* in the *Lieh Hsien Ch'üan chuan* (Complete Biographies of the Immortals) contains the following passage (trans. Wu) which indicates something of the tradition which later attached itself to him.

"One day *Ko Hung* addressed a message to the Governor of Canton stating that he would shortly start on a long journey in search of worthy teachers with whom to study. The Governor made haste to pay him a farewell visit. On that very day *Ko Hung* sat until noon when he died at the age of eighty-one years. He appeared only to have gone to sleep. When the Governor arrived he was already dead. Although dead, he looked alive and his body and limbs were soft. Upon being placed in the coffin, the body disappeared leaving the clothing behind it.

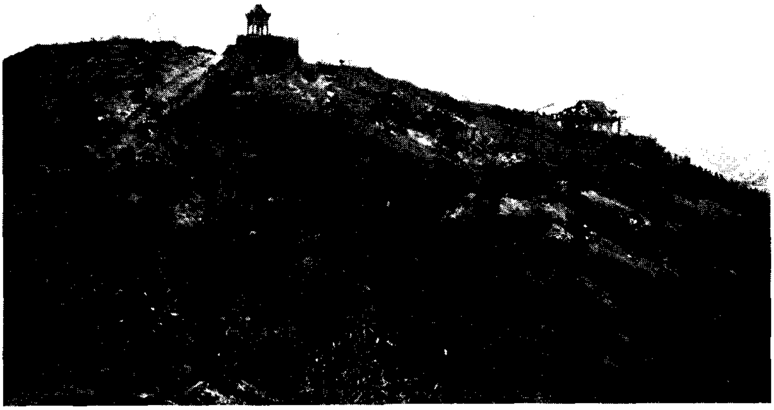
"In the *T'ang* dynasty, one *Tsui Wei* met an aged woman beggar at the *Kai Yuan Tsu* monastery in *Nanhai* who told him of her ability to cure goiters and gave him the medicinal herb, *I*. He later came to the knowledge that she was *Ko Hung's* wife."

In the chapter on the Gold Medicine *Ko Hung* names twenty-seven mountains which are "fit for profound meditation and the compounding of medicines." Besides these "there are large islands which are next in order as places good for the preparation of the medicine" (he names six), and, since "the famous mountains of the central part of the country are inaccessible," he names eight which are accessible. It may be that he visited some of these places. At any rate he is supposed to have lived and experimented on the hill at the West Lake in Hangchow, for the hill is now known as *Ko's* Hill and is surmounted by a Temple dedicated to him, a Medicine Pavilion, and a Shrine containing a stone tablet on which his portrait is carved. The carved portrait shows the same traits of physiognomy, the same beard, the same lines on the cheeks, and the same painted extra set of eyebrows as the other portrait which we have reproduced herewith.



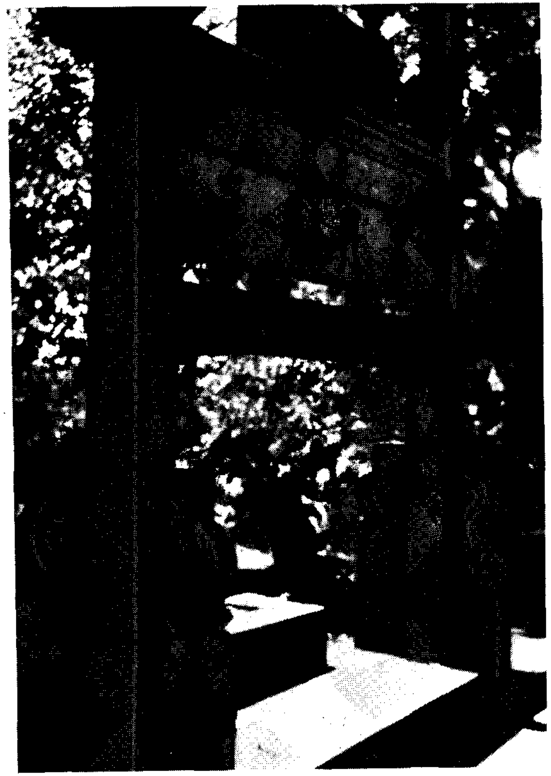
Silk Panel Representing a Scene at the West Lake in Hangchow. The hill shown in the background (now known as *Ko's* Hill) is one upon which *Ko Hung* is supposed to have lived and experimented. A Temple and a Shrine on the hill (not shown in the picture) are dedicated to the master.

It was not customary for a Chinese alchemist to give instruction in the art to a member of his own family. *Ko Hung* therefore did not learn directly from his great-uncle, *Hsien Kung*, but learned from his great-uncle's disciple, *Chêng Chün*. *Pao-p'u-tzŭ* states that *Hsien Kung* had been instructed by *Tso Yüan-Fang* who had received books on the Gold Medicine from a spiritual being. He lists the books on alchemy which *Hsien Kung* received from *Tso Yüan-Fang* and those which he himself received from *Chêng Chün*. He describes some of the conversations which he had had with *Chêng Chün* concerning the principles of the art, and reports that *Chêng Chün* asserted that he and *Tso Chün* had accomplished a successful compounding. He tells in a circumstantial manner about his own instruction and explains his position in seeking the *Tao* and in writing on alchemy. He has always had a liking for unusual information and for things unorthodox. His Outer Chapters and miscellaneous writings in two hundred volumes he considers quite enough to speak his mind to posterity. In the Inner Chapters there are no rhetorical flourishes. He is sure of good results and of the truthfulness of his teachers. Although he



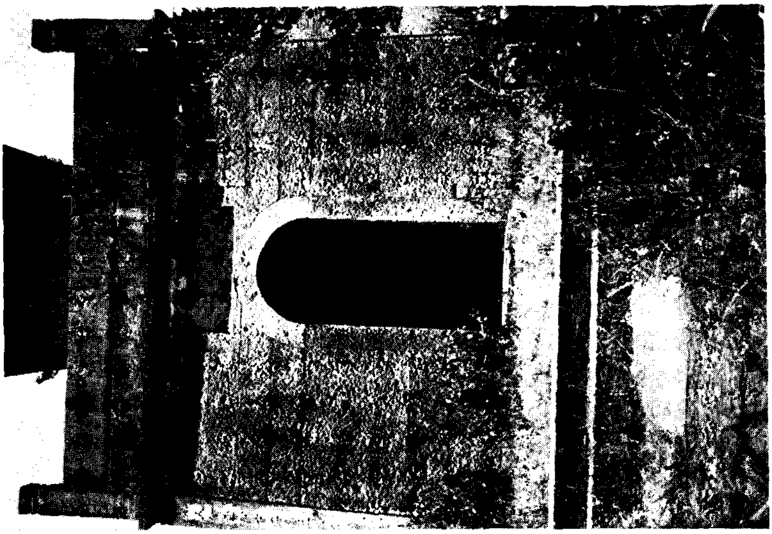
KO'S HILL. THE TABLET SHRINE ON THE HILLTOP AT THE LEFT, THE MEDICINE PAVILION LOWER DOWN AT THE RIGHT.

The Medicine Pavilion

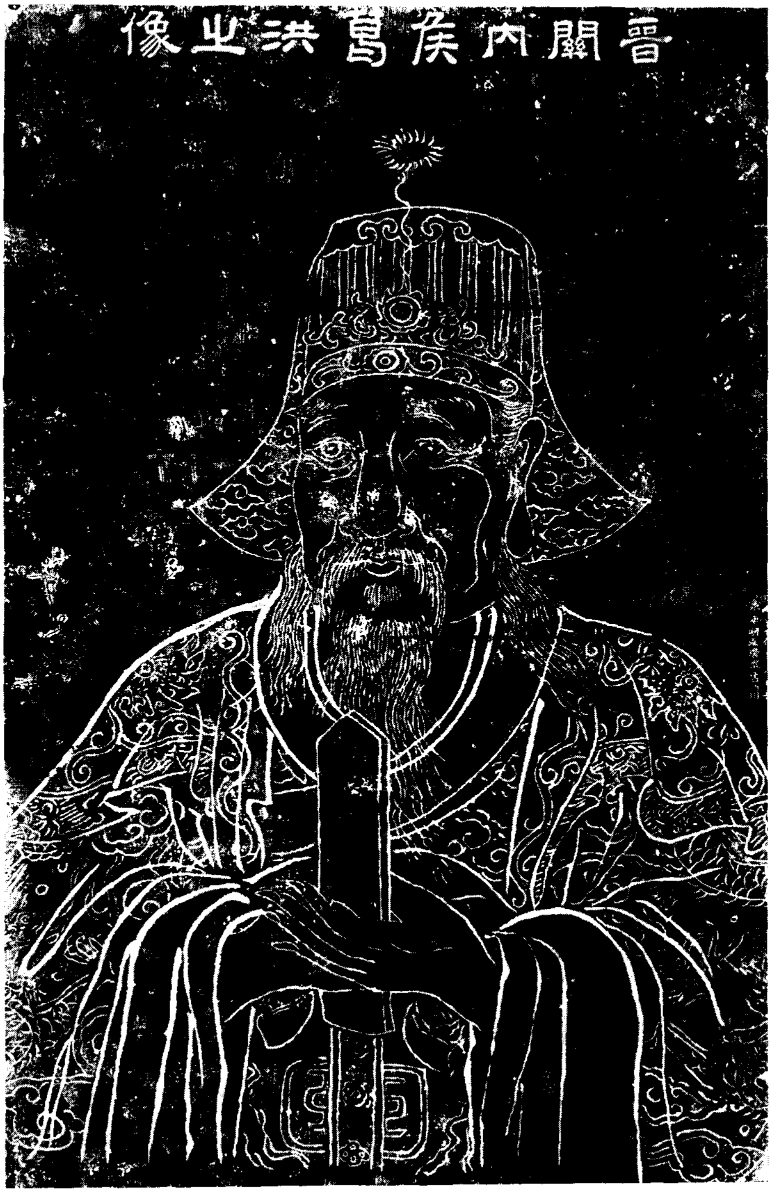


The *P'ailou*, an arch-like gateway of stone, which stands astride the road leading to the Temple. On account of photographic difficulties no picture was made of the Temple itself.

THE MEDICINE WELL. THE INSCRIPTION READS *Chin Ko Hsien Lien Tan Ching*, MEDICINE WELL OF *Ko* THE *Hsien* OF THE *Chin* DYNASTY.



THE TABLET SHRINE WHICH HOUSES A STONE TABLET ON WHICH IS CARVED A PORTRAIT OF KO HUNG.



PRINT OF STONE TABLET PORTRAIT. *Chin Kuan Nei Hou Ko Hung Chih Hsiang*, PORTRAIT OF *Ko Hung*, THE MARQUIS OF *Kuan Nei* OF THE *Chin* DYNASTY.

has not been able to make gold and silver himself, he works hard at his writing for the sake of interesting truth-loving scholars of the future in the study of the *Tao*.

His chapter on the Gold Medicine deals primarily with the preparation of the pill of immortality, and that on the Yellow and White primarily with transmutation—but the two subjects are ultimately the same, for the pill of immortality in certain cases is clearly nothing else but the artificially produced noble metal resulting from the transmutatory process. The Gold Medicine is sometimes the pill of immortality itself, sometimes the product of the transmutation, and sometimes the reagent, the "powder of projection" or the "tincture" as the European alchemists called it, which accomplishes the conversion of the base to the noble metal. In the chapter on the Gold Medicine *Pao-p'u-tzŭ* describes the preparation of the Nine Furnace-Pot Medicines, any one of which will make the user a *Hsien*, and of a large number of other medicines, of varying powers and efficacy, many of which he ascribes to other workers whom he names. Certain ones convert mercury, copper, and lead to gold, another converts lead to silver and to gold, and one in particular converts mercury into silver of such sort that this silver converts further lead into silver, in which respect it resembles the *ferment* of the Mediaeval alchemists. A certain medicine has the power of imparting immortality to one who eats and drinks out of vessels which are made of it, from which it would appear that the medicine is simply actual gold. The inference is verified by passages in the chapter on the Yellow and the White in which the eating of gold and silver is discussed, kneadable gold, and the relative merits of the gold and silver which are found in nature as compared with those which are made by alchemy. Natural and artificial gold and silver are the same, but the *Tao-shih* are too poor to buy the natural metals and find it more convenient to prepare them.

Pao-p'u-tzŭ's insistence upon the genuineness of the gold and silver of alchemy is especially important because of the light that it throws upon the difference between Chinese alchemy and Alexandrian chemistry. His discussion of make-believes shows that he was aware of the possibility of staining the metals and knew that the changes are only superficial and do not correspond to a real change of substance. Iron takes on the appearance of copper if it smeared with *Tsêng Ch'ing*, and silver is given the yellow color of gold by the action of egg-white.

Pao-p'u-tzŭ speaks of the general ignorance of the art and of the pretentiousness of those who are ignorant. He points out that vegetable substances are not suitable materials for the preparation of the medicine, for these, unlike *Tan Sha* (cinnabar), turn to ashes when they are burned. He mentions the necessity for offerings and ceremonials, for isolation from evil and disturbing influences, and for other precautions. He discusses the cost of preparing the medicine and the difficulty of procuring the reagents. He tells anecdotes of certain ones who accomplished, or tried to accomplish, the compounding, and supports his opinions by quotations from earlier sources and by mentioning wonderful things in nature which are well known to be possible. He points out that the secret names by which the substances are designated increase the difficulties, but gives what appear to be very straightforward descriptions of some of the processes. In the chapter on the Yellow and the White in particular, the apparatus and manipulation are sometimes described so clearly that a chemist could carry out the process himself if he knew what reagents to use.

The description of one process deserves special discussion, for it evidently concerns the preparation of stannic sulfide or "mosaic gold" and is perhaps the earliest known description of the preparation of this interesting substance. Mosaic gold exists in flakes or leaflets which have the color and the luster of gold, it does not tarnish, and is used at present for bronzing radiators, gilding picture frames and similar purposes. As *Ko Hung* describes the process, "tin sheets, each measuring six inches square by one and two-tenths inches thick, are covered with a one-tenth inch layer of a mud-like mixture of *Ch'ih Yen* (Red Salt) and *Huei Chih* (potash-water, lime water), ten pounds of tin to every four of *Ch'ih Yen.*" They are then heated in a sealed earthenware pot for thirty days with horse manure (probably with a smouldering fire of dried manure). "All the tin becomes ash-like and interspersed with bean-like pieces which are the yellow gold." The large portion of the metallic tin is converted into some ash-like compound or possibly into the ash-like allotropic modification, gray tin. A small portion of the tin is converted into bean-sized aggregates of flaky stannic sulfide. The yield is poor, for the author says that "twenty ounces of gold are obtained from every twenty pounds of tin used."

It seems likely that *Ko Hung* was personally experienced in the chemistry of tin, for the Chinese say that he was the first to make tin foil and that he made magic or spirit money out of it.

The present translation has been prepared from the *Ch'êng Hsün Shu Yüan* (761, 4881, 10024, 13752) edition of *Pao-p'u-tzŭ*, reprinted and published by the Commercial Press, Ltd., Shanghai, China. The translator has divided it into paragraphs and these have been numbered for readier reference. It has been supplied with an Abstract and Table of Contents which will enable the student more readily to grasp the trends and ramifications of *Ko Hung's* argument and more quickly to find the passages which relate to particular points. When Chinese words are rendered in Roman letters, we have followed the spellings which are used in Giles' Chinese-English Dictionary, 2d ed., London, 1912. As this does not completely identify the words, we have printed, at the places of the first occurrence of the words in the translation, the numbers which correspond to the ideographs in Giles' Dictionary. Later occurrences are indicated in the Index of Chinese Words.

For financial aid in defraying the expenses of the preparation of the translation, we wish to make grateful acknowledgement of a grant from the Permanent Science Fund of the American Academy of Arts and Sciences.

ON THE GOLD MEDICINE

The Fourth of the Inner Chapters of *Pao-p'u-tzŭ*

Translation

1. *Pao-p'u-tzŭ* (8709, 9512, 12317) says: Thousands of books on the cultivation of the nature of man and on the art of everlasting sight have I perused, and every one of them have I found to have nothing other than the *Huan Tan* (5047, 10618) (Returned Medicine) and *Chin I* (2032, 5509) (Gold Fluid) as its main subjects of discourse. From this it may be concluded that these two things are the supreme achievements of the *Hsien Tao* (4449, 10780) (The Immortals' Way, The Way to Immortality). If the eating of these two things does not transform the eater into a *Hsien* (4449), then there could never have been any *Hsien* in the past.

2. There was a time when the country was in tumult and the people fled for safety in all directions. I for one toured through the lands of *Hsü* (4748), *Yü* (13678), *Ching* (2157), *Hsiang* (4266), *Chiang* (1208), and *Kuang* (6397), where I met hundreds of *Tao-shih* (10780, 9992) (Seekers of the Way). Some of them had been known to me through their high reputations. However, all of them were alike in their superficial understanding and in their ignorance even. Every one possessed several tens of volumes of books, but these had been copied only for keeping's sake and were never thoroughly understood. Ever so often these people would profess to have acquired the art of *Hsing Ch'i* (4624, 1064) (the art of directing the movement of the ethereal essence in one's own body) and of thriving on a non-cereal diet of medicinal herbs.

3. All the formula books were very much alike. Every one of the *Tao-shih* had a copy of the *Tao Chi Ching* (10780, 787, 2122) (Book of the Secrets of the *Tao*) and held it to be the most valuable. Yet those people were so ignorant about the book as erroneously to ascribe its authorship to *Yin Hsi* (13270, 4073). So I set them aright by telling them that it was the work of *Wang T'u* (12493, 12128), a military inspector-general of the *Wei* (12567) (403–241 B.C.) dynasty, who was no ancient but just our own contemporary. *Wang T'u* knew nothing about the great medicines, and he was merely attempting to direct the *Ch'i* (ethereal essences in one's body) into the "chamber of achievement" when he wrote the Book of the Secrets of the *Tao*, declaring it to be the complete revelation of the *Tao*. This is indeed very misleading.

4. Upon questioning the *Tao-shih* on the *Shên Tan* (9819, 10618)

(Divine Medicine) and the *Chin I* (Gold Fluid) and on the invocation of *T'ien Shên* (11208, 9819) and *Ti Hsien* (10956, 4449) (Heavenly God and Earthly Spirit), I found that they did not seem to know anything about these things. The majority of them were mere charlatans, who lied to the world when they said that they had been living long among the *Hsien*. As a matter of fact none of them really knew the secrets of the *Tao*. Those of them who had heard something about the Gold Medicine seemed to agree in thinking that its secrets were known only to the ancients who had since become *Hsien*. They did not believe that the Medicine could still be prepared. Again, some of them had secured certain useless formulas and superficial treatises—but never the real book. However, all these people invariably declared that they possessed everything about the art of the Medicine.

5. It was *Tso Yüan-Fang* (11753, 13744, 3455) who, in the midst of profound meditation in the *T'ien Chu Shan* (11208, 2533, 9663) (Sky Pillar Mountain), was given volumes of the divine books on the Gold Medicine by some spiritual being. It was then the close of the *Han* (3836) (206 B.C. to 220 A.D.) dynasty when the land was rife with disturbances. So he fled across the river to come south with the idea of practicing the *Tao* in some famous mountain. From him my great uncle, *Hsien Kung* (4449, 6568), received the *T'ai Ch'ing Tan Ching* (10573, 2188, 10618, 2122) (Book on the Supremely Clear Medicine) in three volumes, the *Chiu Ting Tan Ching* (2263, 11268, 10618, 2122) (Book on the Nine Furnace-pot Medicine) in one volume, and the *Chin I Tan Ching* (2032, 5509, 10618, 2122) (Book on the Gold Fluid Medicine) in one volume. My great uncle in turn passed the books on to his disciple, *Chêng Chün* (724, 3269). *Chêng* was too poor to buy the necessary medicines for the compounding. I had been serving him as a disciple for a long time when we went to the *Ma Chi Shan* (7576, 891, 9663) (Horse Footstep Mountain). There, at an altar especially erected for the purpose and with an oath, I received the book, some magical formulas, and the "Unprinted Magical Formulas." This last book was not known to be in existence until *Tso Yüan-Fang* gave it to my great uncle, who gave it to *Chêng Chün*, who in turn gave it to me. No other *Tao-shih* ever knew of it.

6. It has been more than twenty years since I got the books. Being poor I could only lament the want of means to make trial of the compounding. Yet there are those who have caskets full of gold and mountain-piles of money and know nothing of this art of immortality. They would not believe it even if they heard about it. How unfor-

tunate for these people! Just as one would feel the insipidity of ordinary food only after having tasted a well-flavored dish and sense the smallness of hillocks only after having seen the *K'un Lun* (6537, 7466) Mountain, so would one look down on the common recipes after having learned of the *Chin Tan* (2032, 10618) (Gold Medicine). But the Great Medicine is difficult to compound properly, and so one sometimes has to fall back on the preparation of lesser medicines which are more easily secured. However, the eating of thousands of catties of substances other than the Great Medicine is of little beneficial effect and will not bring immortality to the eater. That is why *Lao-tzŭ* (6783, 12317) remarked that one's efforts would be of no avail unless he succeeded in obtaining the *Huan Tan* or *Chin I.* Even common cereals are capable of supporting the lives of the people; with them they live, without them, they die. How else could it be but that the Divine Medicine would be ten thousand times as efficacious!

7. The more the Gold Medicine is heated, the more exquisite are the transformations it passes through. Yellow gold will not be changed even after long heating in the fire, nor will it rot after long burial in the earth. The eating of these two medicines will therefore so strengthen one's body that he will not grow old and die. This is a case of deriving strength from an external substance, comparable to the maintenance of a fire by oil and the protection of the leg from rotting in water by a smear of *T'ung Ch'ing* (12285, 2184) (Copper Blue). The Gold Medicine which is to be taken internally is even more effective in nourishing and protecting the body than Copper Blue which merely acts on the surface.

8. Numerous are those in the world who do not believe in the *Tao.* There may be a few who do, but they are not so fortunate as to have set eyes on the practice of the Art or even to have heard about it from an accomplished teacher. For the enlightenment of these people I have herewith made a brief transcription of some practical directions for the practice of the Art. The seeker of the *Tao* should not be satisfied with ordinary methods, thinking that they will suffice to bring him immortality.

9. Upon learning the Art one will feel as if he had just come out of a filthy cesspool into the open sea, or left the firefly for the sunlight and moonlight—just as the hearing of peals of thunder makes one feel the insignificance of the roll of the drum, and the sight of a whale makes one feel the smallness of ordinary fish.

10. The attempt at subliming poor medicine is like driving a lame

donkey in pursuit of fast-blowing wind or sailing a basket-like vessel on the high seas.

11. There are numerous minor methods of various kinds for the compounding of the medicine. The efficacy of the medicine compounded does not depend merely on the recipe followed in its making, but varies as well with the degree of working to which it has been subjected. The order of efficacy of the medicines compounded according to various recipes of different values may be reversed on account of different degrees of working, just as wine obtained from a single processing can not be compared with that obtained from nine.

12. However low in value a minor medicine may be, it is still far superior to the best of vegetable substances. For vegetable substances turn to ashes when burned. But *Tan* (10618) (Medicine), when acted upon by heat, gives quicksilver; and, after passing through other changes, it returns to *Tan Sha* (10618, 9620) (Red Sand, Cinnabar). How greatly different from vegetable matter! This is understood only by the *Shên Hsien* (9819, 4449) (Spiritual Beings) who are far superior to common people.

13. In this world there are few who are well-informed and many who harbor misgivings about the *Tao*. Many do not even know that mercury comes out of *Tan Sha*. When told, they still refuse to believe it, saying that *Tan Sha* is red, and how can it produce a white substance? They also say that *Tan Sha* is a stone, and that stones upon heating invariably turn to ashes, and how can *Tan Sha* be expected to behave otherwise? These are but simple truths and yet they are beyond their comprehension. What wonder then that they should laugh at the *Hsien Tao* when told.

14. For the sake of the teachable ones of posterity, the *Chên Jên* (589, 5624) (Truth Men, Sages) of antiquity transmitted a method by which they might be freed from the misery of death. These are indeed words of truth. Even these are looked upon by people of the world as unfounded. How can the words be unfounded when the nine turns and nine transformations (in the preparation of the Medicine) appear several times in a day exactly in accordance with the prescription? The way by which the *Chên Jên* arrived at the truth is indeed beyond common people's reach!

15. Since my youthful days I have had a liking for the Art. I travelled all distances and braved all hazards in my eager search for the Truth. Whenever I succeeded in obtaining some unusual piece of information, I would feel gladdened at heart despite people's ridicule.

16. Not that I want to be known to the world through a book of

strange thoughts and fanciful imagination, but that for the sake of those among people of the future who will appreciate, I am writing this—knowing that all those of later times will be of inferior calibre. Just as the highest degree of *Yang* (12883) (Positiveness) will not revive what is decayed and the greatest mind will not be able to enlighten the most stupid, so books are comprehensible only to those who understand and things are valuable only to those who can appreciate. Give a bow of decoration to a farmer, and he will use it to chase birds away from his farm; give an emperor's robe to a southern barbarian and he will wear it to carry wood. They are simply ignorant. What else can be expected of them?

17. People of the world idle their time away. They neither apply themselves to literary pursuits nor to works. They waste away their lives in pursuit of fame and profit. They may be busy running after official positions in the capital or they may be indulging in wine, woman, song, or the chess, squandering their valuable time to the detriment of their health. Stunned would they be when told of the supreme *Tao*, and bored to dozing by the sight of writings on the *Tao*. They do not take proper care of their nature-given persons. Instead, they seek for their dissipation, ending in death. They do not go after the art of life-cultivation. Of course, those who do not know and value the *Tao* cannot be expected to force it on these unwilling people.

18. People often say that if immortality were attainable, then the wealthy ones among the wise of antiquity would have attained it. In putting forth the argument, these people do not seem to realize that wealthy people of all ages are alike; being disbelievers and not seeking the *Tao*, they concentrate their attention on their immediate needs. How then can they be expected to attain the *Tao?*

19. Even if one does not believe firmly in the possibility of life extension and of becoming a *Hsien*, what is there to deter him from making a trial of the Art? If only a slight success should come of the trial and he should gain thereby two or three centuries of life, would not this slight extension of one's life be far superior to the fleeting existence of the mass?

20. Of the numerous things in this world, the Art and the *Tao* are the most difficult to comprehend. How then can people of ordinary endowment pass the judgement that there cannot possibly be a way to immortality? If one harbors doubts about the *Tao* merely because of popular disbelief, then he is assuming the mass to be wise people. How numerous then will the wise ones in this world be! Furthermore, those who understand the *Tao* and work for its attainment—are they

not the most stupid, even more stupid than common people? Many fear to attempt to seek for immortality, lest they should fail and expose themselves to ridicule as victims of folly and deception. But supposing that common people are not infallible and that their idea about the *Tao* is one mistake they make among ten thousand sound judgements, will not those who have laughed be laughed at by the ones who succeed despite discouragement and ridicule? Even the sun and the moon cannot shine on everything; how can the people's mind be so omniscient as to be entirely trustworthy?

21. *Pao-p'u-tzŭ* says: It is written in the *Huang Ti Chiu Ting Tan Ching* (5124, 10942, 2263, 11268, 10618, 2122) (The Yellow Emperor's Book on the Nine Furnace-pot Medicine) that *Huang Ti* was elevated to a *Hsien* after eating the medicine. Although the proper method of breathing and directing the movements of the *Ch'i* (ethereal essence) of the body, and the eating of vegetable medicine, may extend people's life, yet they will not keep people from death. But the eating of the *Shên Tan* (Divine Medicine) confers immortality on the eater, enabling him to last as long as heaven and earth and to ride on clouds and dragons up and down the *T'ai Ch'ing* (10573, 2188) (Great Clearness).

22. *Huang Ti* transmitted the book to *Hsüan-tzŭ* (4790, 12317), cautioning him that the *Tao* was of great moment and should therefore be made known only to the upright and virtuous and not to any undeserving person even if he were wealthy. He who is ready to follow the *Tao* should send gold effigies as a token of homage, and gold fish into the water which flows eastward, and should besmear his mouth with blood as a sign of allegiance to the cause. No one who is not endowed with bones of *Shên Hsien* will be able to perceive the *Tao*.

23. The medicine should be prepared on a famous mountain, in a lonely spot, with only two or three persons present. The compounder should be on a diet for one hundred days previously and should perfect the purification and anointment of the body with the five perfumes. Meanwhile, strict avoidance of proximity to evil things and complete isolation from vulgarity should be observed. Those who are not believers in the *Tao* and would ridicule the undertaking should be kept in ignorance of it; otherwise the preparation will fail. When the medicine is made, not only will the successful manipulator be immortal, but all the rest of his family will become immortal as well. Common people do not use this method of preparing the *Shên Tan*, preferring instead to use materials of vegetable origin, not knowing that these substances, being themselves subject to decay and destruction when placed in the earth or upon heating, cannot prolong people's lives.

24. The nine preparations, which are so essential to the attainment of immortality, are not what persons of common stamp will ever see or hear of. Those people, numbering millions and millions, stupidly seek for riches and honors and these only. Are they not merely walking corpses?

25. Worship is in order when compounding the medicine. There are separate volumes of diagrams and directions for the service of worship.

26. The first medicine is called *Tan Hua* (10618, 5005) (Medicine Flowers). To begin with, *Hsüan Huang* (4790, 5124) (Black and Yellow, Heaven and Earth, etc.) should be gotten ready. A mixture should be made of some tens of catties of each of *Hsiung Huang Shui* (4699, 5124, 10128) (arsenic sulfide water?), *Fan Shi Shui* (3409, 9964, 10128) (alum water?), *Jung Yen* (5746, 13112) (a red or black salt?), *Lu Yen* (7423, 13112) (niter or potash?), *Yü Shih* (13527, 9964) (a white ore of arsenic?), *Mu Li* (8089, 6970) (chalkstone?), *Ch'ih Shih Chih* (1967, 9964, 1792), *Hua Shih* (5022, 9964) (soapstone?), and *Hu Fên* (4930, 3519) (white lead?). The mixture is then sealed with Six-one Mud. The medicine obtained by thirty-six days heating will confer immortality on the eater in seven days. When mixed with black fat and heated in a strong flame, the medicine will soon turn to yellow gold. This may also be obtained by heating two hundred and forty liangs (ounces) of the medicine with one hundred catties of quicksilver. If yellow gold fails to appear, heating should be repeated and then it will certainly be obtained.

27. The second medicine is called *Shên Tan* (Divine Medicine) or *Shên Fu* (9819, 3687) (Divine Charm) and confers immortality on the eater in a hundred days. He will be able to walk in fire and water uninjured. With this medicine smeared on the soles of his feet he will be able to walk on water. The eating of three knifebladesful of the medicine will kill off all sorts of worms in the body to the end that the eater will be free from all diseases.

28. The third medicine is called *Shên Tan* (Divine Medicine). Whoever eats one knifebladeful of it will become an immortal in one hundred days. Even domestic animals will attain immortality by eating it. It has the power to ward off the five kinds of soldiers. A hundred days after the medicine has been eaten, the *Hsien*, the maids-in-waiting of the spiritual realm, the ghosts and spirits of the mountains and rivers will all come in the form of human beings to wait on the person who has eaten it.

29. The fourth medicine is called *Huan Tan* (Returned Medicine).

Immortality will come to the eater in a hundred days after eating. Above him will hover pheasants, peacocks, and red birds, and at his side will be fairies. Yellow gold will be formed immediately by heating a knifebladeful of the medicine admixed with a catty of quicksilver. Whoever has his money painted with it will have it back on the same day that he spends it. Words painted with this medicine on the eyes of common people will keep spirits away from them.

30. The fifth medicine is called *Êrh Tan* (3343, 10618) (Food Medicine). Immortality will come to its eater in thirty days. Ghosts and spirits will wait on him and fairies will come to his side.

31. The sixth medicine is called *Lien Tan* (7152, 10618) (Refined Medicine). It transforms the eater into an immortal in ten days. Upon heating with quicksilver, it also gives yellow gold.

32. The seventh medicine is called *Jou Tan* (5653, 10618) (Soft Medicine). Whoever eats a knifebladeful of it will become an immortal in a hundred days. The eating of this medicine together with *Ch'ueh P'ên Chih* (3250, 8850, 1789) (Imperfect Basin Juice) is so efficacious as to restore the reproductive activity of an old man of ninety. When heated with *Chin Kung* (2032, 6568) (lead?) it will give yellow gold.

33. The eighth medicine is called *Fu Tan* (3691, 10618) (Latent Medicine). It brings immortality to the eater on the very day that he eats it. The keeping of a quantity of the medicine about the size of the kernel of a date fruit will ward off all evil spirits. Doors with words painted in this medicine will keep off all devils, spirits, thieves, robbers, tigers, and wolves.

34. The ninth medicine is called *Han Tan* (3825, 10618) (Cold Medicine). Whoever east a knifebladeful of it will become an immortal in a hundred days. There will come angels and fairies to wait on him. He will be light of body and will be flying on wings.

35. All these nine medicines need not be eaten. It will be sufficient to eat one of them in order to be a *Hsien*. The choice as to which one among the nine is left to the discretion of the aspirant. Whoever eats any of the medicines may rise on high or stay in this world according to his desire. He becomes invulnerable and is free to move everywhere.

36. *Pao-p'u-tzŭ* says: There is also the *T'ai Ch'ing Shên Tan* (10573, 2188, 9819, 10618) (Supreme Clear Divine Medicine) which originated with *Yüan Chün* (13744, 3269) who was teacher to *Lao-tzŭ*. Of the nine chapters in the *T'ai Ch'ing Kuan T'ien Ching* (10573, 2188, 6363, 11208, 2122) (Supreme Clear Observe Sky Book) the

first three cannot be taught, the middle three are not deserved by the world and should therefore be destroyed, but the last three in three separate volumes are books on the medicine.

37. *Yüan Chün* is a great spiritual being who can harmonize *Yin-Yang* (13224, 12883) (The Two Contraries, Negative and Positive, Female and Male, Soft and Hard, etc.), command ghosts, spirits, winds, and rain, drive the nine dragons and twelve white tigers, and lord over all the *Hsien*. Even this great one was not born with all his powers but acquired them by following the *Tao* and eating the medicine. How can common people expect to get powers otherwise?

38. Says the Book: Among those who have acquired the *Tao*, the best ones will be raised on high to be officials in the skies, the mediocre will congregate on the *K'un Lun* mountain, while the lowest class will be living in this world as immortals. Common people, disbelieving the *Tao*, do things to court death day and night. How can nature be expected to force them to live when they themselves do not seek to do so? One should guard against telling those who care only for delicious food, fine clothes, pleasing tones, pretty faces, wealth, and rank to satisfy their desires to the fullest measure. They will ridicule the *Tao* and the real books on the medicine. He who thus erringly lets out the secrets of the *Tao* will be afflicted with misfortune. To those who have devout faith in the *Tao* some of the medicine may be given but not the directions for making it.

39. He who has attained the *Tao* will have no use for being a prince. For, once the medicine has been prepared, he will not only become an immortal by eating it but he will also be able to make gold out of it. When it has been prepared, a grand offering of a hundred catties of the medicine should be made to the various gods and spirits. The directions for the ceremony of offering are given in another volume and are different from those for the nine furnace-pot offering.

40. The hundred catties of the medicine for the offering are to be apportioned as follows: twenty for worshipping the skies, five for the Sun and five for the Moon, eight for the Great Dipper, eight for the Supreme Monad, five for the well, five for the oven, twelve for *Ho Po* (3936, 9340), five for *Shê* (9803), five for the Spirit of the Gateway, five for the Street-gateway, and five for *Ch'ing Chün* (2188, 3269). The remaining twelve catties should be put in a good leather wallet to be taken on a propitious day at a busy hour to the market, where the material is quietly and unnoticedly disposed of at various places. The one who performs this should not look back at what he has left behind. Whatever is in excess of the one hundred catties will be

available for spending. Misfortune will befall the maker of the gold unless he makes offerings of it to the spirits before spending any of it.

41. The Book says further: The Way to immortality does not lie in the worshipping of and doing service to the spirits, nor in the art of bending and unbending. What is necessary in order to be a *Shên* (9819) (a god, a diety) is the *Shên Tan* (Divine Medicine), which is not so easy to know of and still more difficult to make.

42. Recently, *Hsin Yeh Yin Chün* (4574, 12989, 13224, 3269) of the closing years of the *Han* dynasty succeeded in making this *T'ai Ch'ing Tan* (10573, 2188, 10618) (Supreme Clear Medicine) and with it became an immortal. He was a Confucian of parts, adept at poetical composition and the writing of commentaries on books and on the medicine. From his pen (brush) came also an account of his early experiences in learning the *Tao* from a certain teacher and of forty people whom he personally knew to have been transformed into spiritual beings.

43. The preparation of this Supreme Clear Medicine is more difficult than that of the Nine Furnace-pot Medicine. However, it is the means to make one raised on high in broad daylight. Before starting the fire for the compounding, *Hua Ch'ih* (5005, 1983) (Flower Pond), *Ch'ih Yen* (1967, 13112) (Red Salt), *Kên Hsueh* (5972, 4845), *Hsüan Pai* (4790, 8556) (Black-White), *Fei Fu* (3483, 3687), and *San Wu Shên Shui* (9552, 12698, 9819, 10128) (Three-Five Divine Water) should be made.

44. The eating of the medicine of the first turn will bring immortality in three years, that of the second turn in two years, of the third in one year, of the fourth in one-half year, that of the fifth turn in one hundred days, of the sixth in forty, of the seventh in thirty, of the eighth in ten, and of the ninth in three days.

45. When the medicine of the ninth turn is placed in a Divine Furnace-pot in the sun sometime after the summer solstice until the pot becomes hot, and then a catty of *Chu Êrh* (2544, 3333) (Red Substance) is placed under the lid, it will be noticed by a couching observer, after the sun-spirit has shone on it for a short time, that the substances are raised in dazzlingly brilliant divine lights of rainbow colors. That is the Returned Medicine, the eating of a knife-bladeful of which will raise the eater to the skies in broad daylight.

46. The medicine of the ninth turn may be sealed in a kettle and heated by sawdust, gently at first and then strongly. The speed of transformation is variable from the first change to the ninth. The medicine of fewer turns is less efficacious and will confer the state of

Hsien on its eater only after a lapse of time. The medicine of more turns is more powerful and will do the same in less time.

47. There is also the *Chiu Kuang Tan* (2263, 6389, 10618) (Nine Light Medicine) prepared according to the *Chiu Chuan I Fa* (2263, 2711, 5505, 3366) (Marvellous Method of Nine Turns). This is similar to the one just described. In its making the several medicines are fired together so as to turn the five stones, which are, namely, *Tan Sha* (cinnabar), *Hsiung Huang* (4699, 5124) (arsenic sulfide?), *Pai Fan* (8556, 3409) (white alum), *Tsêng Ch'ing* (11735, 2184) (a blue compound of copper?), and *Jui Shih* (5723, 9964). Each stone can make five turns of five different colors. The five stones together can give twenty-five different colors. One liang (ounce) of each should be placed in separate vessels.

48. To resuscitate a person who has been dead for less than three days, bathe the body in a mixture of a knifebladeful of *Ch'ing Tan* (2184, 10618) (Blue Medicine) and water, and feed him with another knifebladeful. Under such treatment he will be immediately raised from the dead.

49. He who has his left hand painted with some of the black medicine admixed with a little water will be able to get whatever he desires.

50. If one desires to disappear at will, to foresee the future, to tell fortunes, to have eyesight covering thousands of miles, and to be immortal, he needs only to partake of a knifebladeful of the Yellow Medicine. All these are to be found in the middle volume of the *T'ai Ch'ing Ching* (10573, 2188, 2122) (Supreme Clear Book).

51. *Pao-p'u-tzŭ* says: There is also the *Wu Ling Tan Ching* (12698, 7222, 10618, 2122) (Book on Five Efficacious Medicines) in one volume, which treats of five methods. The materials to be used are *Tan Sha, Hsiung Huang, Tz'ŭ Huang* (12397, 5124) (arsenic sulfide?), *Tsêng Ch'ing, Liu Huang* (7245, 5124) (sulfur), *Fan Shih* (3409, 9964) (alum?), *Ts'ŭ Shih* (12407, 9964), *Jung Yen,* and *T'ai I Yü Liang* (10573, 5341, 13615, 7016) (Remains of Provisions of the Supreme Monad). With *Liu I Ni* (7276, 5342, 8197) (Six-one Mud) these are to be compounded in a divine chamber with proper ceremonies, offerings, and worship. The medicine is made in thirty-six days. A *Wu Ti* (12698, 10942) (Five Emperors) charm painted with the medicine in five colors has the power to bring about immortality. However, this is not as efficacious as the medicines prepared according to the Supreme Clear Method or the Nine Furnace-pot Method previously described.

52. The *Min Shan* (7910, 9663) (Min Mountain) Method is due to *Chang Kai Ta* (416, 5784, 10489) to whom it was revealed in the midst of his profound meditation in a stone chamber in the *Min* Mountain. It is as follows: A vessel of *Huang T'ung* (5124, 12285) (Yellow Copper, Brass?) for the reception of water from the moon is covered with quicksilver and the spirit of the sun is allowed to fire its inside. Repeated eating of the medicine thus prepared will bring immortality. This medicine may be further treated with *Hsiung Huang* in a sunlight-concentrator of copper (bronze) under a covering of quicksilver and exposed to sunlight for twenty days. When a pea-size quantity of the medicine thus prepared is swallowed with some water, if a blind man takes it, he will regain his sight in a hundred days; if an invalid, he will recover his health in the same lapse of time; if a hoary head, his hair will turn black again; and if short of teeth, new ones will grow in place of those which had fallen.

53. In the preparation of *Wu-ch'êng-tzŭ's* (12790, 762, 12317) medicine, *Huan Sha Hung* (5047, 9624, 5266) (Return Sand Mercury) is placed in an eight-inch copper (bronze?) plate, which rests on three points of an earthenware stove containing burning charcoal. To the contents of the copper plate sulfur is added from time to time so as to maintain a pasty condition. It takes one hundred days to complete the preparation of the medicine, an elixir.

54. *Hsien-mên-tzŭ's* (4546, 7751, 12317) medicine is prepared by having a mixture of one part of *Tan* and three parts of wine exposed to the sun for forty days. On the first day of eating, the three kinds of worms and all maladies are banished. By eating it regularly for three consecutive years one attains the *Tao*. There will come two fairies to wait on him. His will be the power to get whatever he desires. All spirits and dead ones are kept from doing any harm in the presence of this medicine.

55. The *Li Ch'êng Tan* (6954, 762, 10618) is similar to the Nine Furnace-pot *Tan* but is not as efficacious. One way of preparation is to fire *Tz'ŭ Huang* and *Hsiung Huang* to get copper for casting into a vessel, which is then inverted over some three-year old wine. Red stalagmites of less than an inch in length or five-colored precious stones will appear inside the vessel in a hundred days. These are then removed and placed for some time in the earth to obtain the elixir. By eating this medicine with the sap of *T'u Ssŭ* (12124, 10259) one gains the power to transform himself into anything he desires. He who swallows the medicine together with some *Chu Ts'ao* (2544, 11634) (Red Herb) is empowered to walk on emptiness. The Red Herb, often

found in caves, is similar to the small date and attains a height of three or four feet when full-grown. Its branches and leaves are all red and its stems are like corals. When tapped, its sap flows out like blood. By adding jade, the eight stones, gold, and silver to the sap, a thick paste is obtained which may readily be made into pills. On standing the thick paste changes to a liquid which is called *Yü Li* (13630, 6950) (Sweet-wine of Jade).

56. Again, there is the *Ch'ü Fu Tan* (3118, 3727, 10618). In the famous *Tan* (medicine, red) rivers, such as the *Tan* river of *Nan Yang* (8128, 12883), there are *Tan* fishes at night-time ten days before the summer solstice, at which time they are found to be swimming along the borders of the waters with their dazzling colors shining through like blazing fire. They should then be caught in nets. However, only a portion of the catch should be taken and the rest should be returned to the water. He who has his feet painted with the blood of such fish is thereby enabled to walk on the surface of water and to live in the deeps.

57. The preparation of the medicine according to *Ch'ih-sung-tzŭ* (1967, 10449, 12317) is as follows: *Tan*, covered with the sweat of an old mud container made of vegetable fiber, and the juice of "alum peach" are sealed in a waterproof vessel, which is then buried three feet below the surface of the earth for a hundred days. When mixed with the juices pressed from the red seeds of the *Chu* (2606?) tree and eaten, this medicine will bring redness to the features and hair as well as immortality. It is not improbable that the Red Beards among the Yellow *Hsien* were eaters of this medicine.

58. In *Shih Hsien Shêng's* (9964, 4440, 9865) preparation, the young unfledged "black birds" are fed with real *Tan* and beef. When grown up, they have red down and feathers. They are then to be killed and crushed together with their feathers. A knifebladeful of this medicine taken internally will bring a long life of five hundred years.

59. The medicine of *K'ang-fêng-tzŭ* (5908, 3554, 12317) is compounded by mixing *Tan* with "sheep black," crane's eggs, fowl's blood, *T'ien Hsiung* (11208, 4699), and juice of Mount *Shao Shih*. The mixture is then sealed inside the shell of an egg of the *Ku* (6248) (heron) and soaked in *Yün Mu Shui* (13812, 8067, 10128) (mica water?) for a hundred days. A dose of one tenth of a quart of the red liquid thus obtained prolongs life for ten years and a quart of it brings a long life of a thousand years.

60. According to *Ts'ui-wên-tzŭ* (11917, 12633, 12317), the medicine

obtained by stuffing *Tan* inside the *Wu* (8085) (a kind of duck?) effects an extension of life when swallowed occasionally and brings immortality when eaten regularly.

61. *Liu Yüan* (7270, 13744) prepared his medicine by soaking *Tan Sha* in *Hsüan Shui* (4790, 10128) (Black Water, Mystic Water) for a hundred days. It turns purple and will not soil the hands. It is next mixed with *Yün Mu Shui* (mica water?), sealed in a tube, and placed in a well. At the end of a hundred days the mixture is transformed into a red liquid. When taken internally, one tenth of a quart of this medicine enables one to live a thousand years; habitual drinking of it brings immortality.

62. In preparing his medicine, *Lo-ch'ang-tzŭ* (7331, 450, 12317) placed some *Tsêng Ch'ing, Ch'ien Tan* (1733, 10618) (Lead Red), quicksilver, and *Tan Sha* in a copper vessel. This is then sealed with dry tile and white soapstone (slate?) and heated in white sand for eighty days. By swallowing a pea-size quantity of this medicine, one will attain the state of a *Hsien* in three years.

63. In *Li Wên's* (6884, 12633) preparation *Tan* is wrapped in raw silk and boiled in bamboo sap to get the Red Springwater. This is then floated on water and cooked. A potion of one tenth of a quart of a mixture of this medicine with *Hsüan Shui* will bring about the state of *Hsien* in a year.

64. The preparation of the medicine according to *Yin-tzŭ* (13270, 12317): Have a mixture of *Yün Mu Shui* (mica water?) sealed in a vessel to be buried in a Gold Flower Pond for a year. A catty of this medicine ingested in knifebladeful doses confers on the eater a long life of five hundred years.

65. The compounding of the *T'ai I Chao Hun P'o Tan* (10573, 5341, 466, 5244, 9420, 10618) (The Supreme Monad's Medicine for the Summoning of the Spirit) is similar to that of the *Chiu Kuang Tan* (The Nine Light Medicine) in the use of the five stones and the sealing of the vessel with Six-one Mud. When swallowed with a *Liu Huang* (sulfur) pill and some water, this medicine has the power of reviving persons who have been dead for three days or less. Life comes back to these persons instantly. Those who have been revived in this manner invariably tell the story that they followed the beckoning of a messenger on their return to this world.

66. The *Ts'ai Nü Tan* (11504, 8419, 10618) is prepared by cooking *Tan* with hare's blood and honey for a hundred days. He who swallows pills of this medicine of the size of a dryandra seed, one pill at a time and three times a day for a hundred days, will have two fairies at his service.

67. To prepare the medicine of *Chi-ch'iu-tzŭ* (904, 2310, 12317), clear and colorless wine, sesame oil, sweet-wine of a hundred blossoms, and dragon fat, enclosed with *Liu I Ni* (Six-one Mud), are heated for ten days by a flameless fire of husks. The ingestion of this medicine in pea-size doses will bring a long life of five hundred years.

68. In compounding *Mo-tzŭ Tan* (8022, 12317, 10618), mercury and Five Stone Fluid are cooked for ten days in a copper vessel with stirring by an iron ladle. A knifebladeful of the Returned Medicine thus obtained is sufficiently potent as a panacea. Habitual ingestion brings immortality.

69. When lead, mercury, *Tsêng Ch'ing*, and water are sealed together and cooked in red millet seeds for eighty days the *Chang-tzŭ Ho Tan* (416, 12317, 3945, 10618) is obtained. Regular ingestion of pea-size pills made of this medicine and some date meal for a hundred days brings a long life of five hundred years.

70. The elixir of *Ch'i Li* (998, 6870) is a five-colored medicine compounded by cooking the five-stones, snow, *Tan Sha*, and mercury in a large copper vessel for a hundred days.

71. By firing together a hundred knifebladesful of the *Ch'i Li* medicine and a hundred catties of lead, white silver will be obtained. Upon firing it with *Hsiung Huang* for a hundred days, yellow gold is formed which, if too hard, may be softened by boiling with lard, and if too soft, may be hardened by boiling with some white plums.

72. The *Yü Kuei Tan* (13630, 6435, 10618) is made in the following manner: *Tan* is moistened with saliva and placed between two layers of a mixture of *Tsêng Ch'ing* and sulfur powder in a bamboo pipe which is heated in a sand bath for fifty days. He who has taken this medicine internally for a hundred days will have fairies and spirits (such as those who have control over the elements, etc.) at his service and he will be a seer.

73. In making the *Chou Hou Tan* (2474, 4025, 10618) saliva and *Tan* are mixed, sealed in dry tile, and cooked for eighty days. A pea-size quantity of the substance obtained is then stirred in the sun so that the light coming from it mixes with the sunlight. A pea-size amount of this medicine is enough to bring about immortality. When fired in copper of *Tan Yang* (10618, 12883), this medicine is transformed into gold.

74. The medicine of *Li Kung* (6884, 6568) is prepared by mixing *Chên Tan* (589, 10618) (Real Medicine) with one quart each of the waters of the five-stones so as to form a thick paste. After firing in a caldron for thirty-six days, *Shih Liu Huang I* (9964, 7245, 5124,

5509) (Stone Sulfur Liquor) is added and mixed. Ten years' regular ingestion of the medicine thus prepared will enable a man to last as long as the sky and the earth.

75. To compound the medicine of *Liu Shêng* (7270, 8965), *Tan* admixed with the juices of the *Ti Ch'u* (10956, 2649) herb, the *Ch'u* (2627) tree, and chrysanthemum flowers is heated for thirty days and then ground to a powder. A year's eating of this medicine will bring a long life of five hundred years. If the eater be an old man, he will be rejuvenated beyond recognition; if a youth, he will not grow old.

76. The medicine of *Wang Chün* (12493, 3269) is made as follows: *Pa Sha* (8510, 9624) and mercury are sealed in eggs, which are then brooded by a hen. Ageing and decay of the human body will be avoided by eating three such eggs on a propitious day. Children should not be allowed to swallow them, else they will be stunted in their bodily development. The same result obtains with new-born chickens, dogs, and all other fowls and animals.

77. The preparation of the medicine of *Ch'ên Shêng* (658, 9865) consists of sealing some white honey and *Tan* in a copper vessel, which is then placed in the water of a well for a year. The eating of this medicine protects one from hunger for a year. The consumption of a catty of the medicine makes one live a hundred years.

78. The medicine of *Han Chung Chung* (3827, 2900, 2894) is made by cooking honey and *Tan* in a sealed vessel. He who eats it will have his life prolonged, the strength of his eyesight improved, and no shadow cast from his person when standing in the sun. Besides the methods of preparation of the medicine just described, there are still others, which, however, need not be discussed here.

79. *Pao-p'u-tzŭ* says: *Chin I* (Gold Fluid) is what *T'ai I* (10573, 5341) (the Supreme Monad) swallowed and was thereby transformed into a *Hsien*. Its efficacy is no less than that of the nine medicines. In its making one pound (old weight) of yellow gold is sealed in a vessel together with *Hsüan Ming Lung Kao* (4790, 7946, 7479, 5936) (Dark Clear Dragon Grease), *T'ai I Hsun Shou Chung Shih* (10573, 5341, 4864, 10014, 2875, 9964) (Stone in the Head of the Supreme Monad), *Ping Shih* (9277, 9964) (Ice-Stone), *Tzŭ Yu Nü* (12329, 13423, 8419) (Purple Itinerant Damsel) *Hsüan Shui I* (4790, 10128, 5509) (Dark Water Fluid), *Chin Hua Shih* (2032, 5001, 9964) (Gold Petrified Stone), and *Tan Sha*. The mixture changes into a fluid in a hundred days. According to the *Chên Ching* (589, 2122) (Real Book), the swallowing of the Gold Fluid causes the whole body to assume a gold color. *Lao-tzŭ* transmitted the secret to *Yüan Chün*, saying

that the *Tao* was of great import and that, since it came to light only once in about a hundred years, he should preserve the secret well in a stone chamber inside a special building by the side of an eastward-flowing stream on the side of a celebrated mountain. The process occupies a hundred days, during which time the compounder should be dieting and be isolated from the mass. A dose of a liang (ounce) of the medicine will transform one into a *Hsien*, who however shall remain in this mundane world and shall be known as a *Ti Shui Hsien* (10956, 10128, 4449) (An Immortal of the Earth and Waters). In order to be raised to the skies, one must abstain from eating cereals for a year before swallowing the medicine. One-half liang of the medicine will bring immortality and immunity from all evils and maladies. He will be able to raise a family and to rank in officialdom to the full of his desires. Those who desire to ascend to the skies should diet and should swallow an ounce of the medicine.

80. The method of *Chin I Wei Wei Hsi Chü Shêng Fa* (2032, 5509, 12521, 12582, 4073, 3003, 9876, 3366): After cooking for thirty days, a mixture of *Chin I* (Gold Fluid) and quicksilver is placed in a yellow earthen jar, which is then sealed with Six-one Mud and strongly heated for sixty hours. Thereupon the medicine is obtained. The swallowing of a pea-size quantity of the medicine is enough to make a *Hsien* out of any person. Silver is obtained by sprinkling a knife-bladeful of this medicine onto a catty of quicksilver. When a catty of the medicine is placed over a fire and fanned, red gold is obtained, which will flow and is called *Tan Chin* (10618, 2032) (Medicine Gold). Swords besmeared with this medicine have the power of checking enemies at a distance of ten thousand miles. By eating and drinking out of vessels made of this medicine, one will attain immortality. The medicine may be exposed to the sun and moon to obtain a liquid which is also an elixir. When a mixture of the Gold Fluid and Yellow Earth is strongly heated in a jar made of Six-one Mud, it is entirely changed into serviceable yellow gold.

81. When the latter is again heated *Tan* is obtained, a pea-size dose of which is potent enough to make one a *Ti Hsien* (Earthly Spirit, an Immortal of the Earth) in celebrated mountains and great rivers. Silver is obtained when a knifebladeful of this medicine is sprinkled onto quicksilver. When an ounce of this silver is mixed with a catty of lead the entire mass is changed into silver. He who desires to get the classic on the Gold Fluid and the magic chant must throw eight ounces of gold into an eastward flowing river and must take an oath by smearing his lips with blood. No success will come

to him who obtains the secrets in an irregular way. Even to those who are professedly the most credulous, only the medicine should be given but not the classic which deals with its making. The indiscreet giving of the classic will bring misfortune both to the giver and to the recipient. For the gods watch over us closely without our knowledge.

82. *Pao-p'u-tzŭ* says: True it is that the nine medicines are the best of *Hsien* medicines. Yet the materials for their compounding are quite numerous. They are easily procurable only in large cities which have good facilities for communication, but are not to be obtained at other places. Furthermore, in the compounding of the medicines, the fires should be tended for tens of days and nights with industrious application and close adjustment, which is a great difficulty. The compounding of the Gold Fluid is much easier. There the only thing which is difficult is to get the gold. One pound in the old measure is equivalent to two in our contemporary measure. Such a quantity of gold would cost only some three hundred thousand cash. The other auxiliary materials are easy to procure. In the compounding, no fire is required. All that needs to be done is to have the mixture in a *Hua Ch'ih* (Flower Pond) for the necessary number of days. A total expenditure of four hundred thousand cash will make an amount large enough to transform eight persons into *Hsien*. Just as no wine is formed by the fermentation of small quantities of rice, so small quantities of materials will not be able to interact to give the medicine.

83. *Pao-p'utzŭ* says: Again there is the *Êrh Huang Chin* (3343, 5124, 2032) (Food of Yellow Gold) which, although not as good as Yellow Gold, is yet by far better than other medicines. Gold may be refined by the use of pig's skin and hide fat, or by treatment with the bark of the *Ch'u* herb, or by having it pulled out into sheets, or by transforming it all at once into a fluid. Again *Hsiung Huang* and *Tz'ŭ Huang* may be used to treat the gold to yield something stretchable like skin. All these are but methods of the *Ti Hsien* (Immortal of the Earth).

84. Both silver and large pearls of the oyster can be made into water, which is a medicine that will not keep and will bring immortality only through frequent ingestion. So it is not as good as the Gold Fluid.

85. *Pao-p'u-tzŭ* says: In compounding the Gold Fluid and the Nine Medicines, it is necessary not only to spend money but also to carry out the work in celebrated mountains in complete isolation from

the work-a-day world. That is why few persons are successful in it. The printed word is sure to spread. Since such secrets should be guarded from the mass, so books on the *Tao* should never deal with the Gold Medicine.

86. In compounding the medicine the chief thing to be guarded against is the ridicule of the disbeliever. For such derision is sure to prevent the success of the compounding. According to the words of *Chêng Chün*, he who attempts the compounding of this medicine must make offerings to the gods, from among whom *T'ai I* (Supreme Monad), *Yüan Chün*, *Lao Chün* (6783, 3269), and *Hsüan Nü* (4790, 8419) will come to watch over the operations. If the compounder should let stupid people of the world know of his doings by not working in a secluded place, the gods would withhold their blessings, whereupon the evil *Ch'i* (ethereal essence) would enter to spoil the medicine. In order to be successful the compounder must work in a famous mountain retreat in isolation from the mass. He should practice dieting, refraining from the five stimulant foods, namely, *Ts'ung* (12021) (Leeks), *Suan* (10381) (garlic), *Chiu* (2279) (scallions), *Liao Hao* (7067, 3871) (smartweed), and *Chieh* (1525) (mustard), and from raw fish, for a hundred days before beginning to work and continued until the medicine is done.

87. *Chêng Chün* says that, according to what he heard from *Lao Chün*, the attempted preparations of the Gold Fluid and the Divine Medicine should never be made in small mountains, where there are no real gods but spirits of trees and stones, aged things of ten thousand years and bloodthirsty demons. These are devils who work not for the good but for the evil of man. They attempt to lead seekers of the *Tao* astray into temptation. The seekers should protect themselves and their retainers against these devils who may do harm to their medicines. In preparing good medicines, medical men of today guard against the sight of chickens, dogs, children, and women, lest the efficacy of their medicines be destroyed by the evil sight of these things. Likewise, dyers guard their goods from the sight of the evil-eyed, lest the beautiful tints be spoiled. What wonder then that the great medicines of the gods should be closely guarded? That is the reason why seekers of the *Tao* since ancient times do their compounding not in ordinary but in famous mountains.

88. According to the *Hsien Ching* (4449, 2122) (Book of Immortals), the mountains fit for profound meditation and the compounding of medicines are as follows: *Hua Shan* (5005, 9663) (*Hua* Mountain), *T'ai Shan* (10596, 9663), *Ho Shan* (3979, 9663), *Hêng*

Shan (3919, 9663), *Sung Shan* (10458, 9663), *Shao Shih Shan* (9746, 9974, 9663), *Ch'ang Shan* (450, 9663), *T'ai Pai Shan* (10573, 8556, 9663), *Chung Nan Shan* (2894, 8128, 9663), *Nü Chi Shan* (8419, 837, 9663), *Ti Fei Shan* (10956, 3497, 9663), *Wang Wu Shan* (12493, 12737, 9663), *Pao Tu Shan* (8709, 12065, 9663), *An Ch'iu Shan* (44, 2310, 9663), *Ch'ien Shan* (1739, 9663), *Ch'ing Ch'êng Shan* (2184, 763, 9663), *O Mei Shan* (8430, 7714, 9663), *Sui Shan* (10392, 9663), *Yün T'ai Shan* (13812, 10577, 9663), *Lo Fu Shan* (7291, 3646, 9663), *Yang Chia Shan* (12883, 1154, 9663), *Huang Chin Shan* (5124, 2032, 9663), *Pieh Tsu Shan* (9154, 11826, 9663), *Ta T'ien T'ai Shan* (10470, 11208, 10583, 9663), *Hsiao T'ien T'ai Shan* (4294, 11208, 10583, 9663), *Kai Chu Shan* (5784, 2616, 9663), *Kua Ts'ang Shan* (6288, 11596, 9663). In these mountains there are true gods and perhaps *Ti Hsien* (Immortals of the Earth). On them grows the *Chih Ts'ao* (1788, 11634) (Herb of Longevity). These mountains are good, not only for compounding medicines, but also as refuges from military and other dangers. Those who have attained the *Tao* will be helped to success by the gods in their attempts at compounding the medicines.

89. Besides the mountains before-mentioned, there are large islands which are next in order as places good for the preparation of the medicines, namely, *Tung Wêng Chou* (12248, 12667, 2445), *Tan Chou* (10641, 2445), and *Chu Yü* (2606, 13523) in the district of *Hui Chi* (5184, 884), *Yang Lü Chou* (12842, 7520, 2445), *T'ai Kuang Chou* (10596, 6389, 2445), and *Yü Chou* (13535, 2445) in the district of *Hsü Chou* (4748, 2444).

90. The famous mountains of the central part of the country are inaccessible. The accessible ones are *Ho Shan*, *An Ch'ang Shan* (44,450, 9663), and *T'ai Pai Shan* which are in the district of *An Yang* (44, 12883), and *Ssŭ Wang Shan* (10291, 12509, 9663), *Ta T'ien T'ai Shan*, *Hsiao T'ien T'ai Shan*, *Kai Chu Shan*, and *Kua Ts'ang Shan* which are in the district of *Hui Chi*.

91. *Pao-p'u-tzŭ* says: Although I come from a family of high officials, I have no ability to manage affairs of state. Yet I could have attained fame and high official rank if I had followed the footsteps of my kinsmen who, although far less accomplished than I, have risen high in officialdom. For the sake of writing and compounding the Divine Medicines for the attainment of immortality in far-away mountains, I have left behind me my people and worldly honors. People of the world look askance on my abandonment of officialdom and on my isolation from the mass to take up the labor of farming. Some even say that I am out of my mind. But it should

be remembered that the *Tao* and the affairs of the world are incompatible. How could I seek for the *Tao* without abandoning worldly affairs? When sure of his convictions, one acts accordingly with determination, unaffected by praise or by blame, by encouragement or by dissuasion from others. I write of my intentions so as to make them known to men of the same mind of the future. Men of determination who come after me will have to make sacrifices similar to mine.

92. The *Hsiao Shên Tan Fang* (4294, 9819, 10618, 3435) (Formula of the Lesser Divine Medicine) is as follows: Three catties of Real *Tan* and six catties of white honey are mixed and cooked in the sun until the mass can be made into pills. Within a year after consuming a dose of some ten pills of the size of sesame seeds, gray hair will turn black, fallen teeth will be replaced by new ones, and robustness will spread all over one's appearance. Frequent swallowing of the pills will bring rejuvenation and immortality.

93. The *Hsiao Tan Fa* (4294, 10618, 3366) (Method of the Lesser Medicine): One catty of *Tan*, after proper grinding and sieving, is thoroughly mixed with three quarts of bitter wine and two quarts of lacquer. The intimate mixture is heated over a gentle fire until it can be made into pills. The swallowing, daily for thirty days, of three pills of this medicine of the size of sesame seeds will cure the hundred sicknesses and dispel the three demons (one in the brain, one in the heart, and one in the abdomen; they cause the diseases in people). He who continues swallowing the medicine for a hundred days will have strong bones and sinews. He who does it for a thousand days will have his name engrossed on the list of the immortals and will last as long as heaven and earth. Form and complexion change irregularly. The sun and the moon become full by turns. He will not cast any shadow in the sun, for he will give off a special light.

94. The *Hsiao Êrh Huang Chin Fa* (4294, 3343, 5124, 2032, 3366) (Method of the Lesser Food of Yellow Gold): Refined gold is placed in clear wine and boiled until, when squeezed in the hand, it comes through between the fingers like mud. If the mixture does not boil, or if it does not come through between the fingers, the gold should be cut into smaller pieces and then boiled again with wine. He who swallows one shot-size pill of the medicine, or two small ones of half that size, daily for thirty days will be cared for by the gods and fairies. Silver may be used instead of gold in the preparation of the medicine. He who eats these two medicines will attain buoyancy of movement if he lives in a stone chamber in a famous mountain, and

he will be an immortal of the earth if he stays among the mass. This secret should not be divulged without discretion.

95. The *Liang-i-tzŭ Êrh Hsiao Huang Chin Fa* (7010, 5455, 12317, 3343, 4297, 5124, 2032, 3366) (Method of the Food of Reduced Yellow Gold of *Liang-i-tzŭ*): Three catties of hog's skin and adhering fat, one quart of clear bitter wine, and five ounces of yellow gold are heated in a vessel in an earthen oven. The gold will make a hundred entrances and a hundred exits from the fat. So will the wine. A dose of one catty of the medicine will bring immortality; one-half catty, two thousand years of life; and five liangs (ounces), twelve hundred years of life. There is no limit to the quantity of the medicine to be eaten, but propitious days should be chosen for its eating. The secret should not be divulged to others, else the medicine cannot be prepared successfully.

ON THE YELLOW AND THE WHITE

THE SIXTEENTH OF THE INNER CHAPTERS OF *Pao-p'u-tzŭ*

TRANSLATION

1. *Pao-p'u-tzŭ* says: *The Shên Hsien Ching* (9819, 4449, 2122) (Book of Spiritual Beings, Book of Deities and Immortals) dealing with *Huang Pai* (5124, 8556) (The Yellow and the White) comprises twenty-five volumes of over a thousand sections. The Yellow is gold and the White is silver. Unwilling to mention them outright, the ancients spoke of these substances enigmatically so as to keep the valuable *Tao* in secrecy. Sometimes they entitled their writings *Kêng Hsin* (6001, 4564), which also means gold. Most of the writings are difficult to comprehend, while only a very small part of them is definitely understandable. Common people seem to think that the *Tao* is merely fictitious. Such misgivings are the same thing as disbelief in *Shên Hsien*.

2. Sometime ago, as a disciple of *Chêng Chün*, I received the *Chiu Tan Chin* (2263, 10618, 2122) (Book of Nine Medicines), the *Chin Yin I Ching* (2032, 13252, 5509, 2122) (Book of Gold and Silver Fluid), and the *Huang Pai Chung Ching* (5124, 8556, 2875, 2122) (Middle Book of the Yellow and the White) in five volumes.

3. *Chêng Chün* said that he and *Tso Chün* (11753, 3269) had attempted the compounding with success in *T'ung Shan* (12285, 9663) (Copper Mountain) on the *Lu Chiang* (7396, 1208) (Lu River). The diligence and hardships sustained from dieting, purification, and abstinences are no different from those incidental to the compounding of *Chin Tan* and *Shên Hsien Yao* (9819, 4449, 12958) (Divine Medicine, Medicine of Spiritual Beings).

4. Most people ridicule me for my liking for things unorthodox. They take me to be queer for attempting to understand the incomprehensible. But why should I do so? Am I writing on these things just for the sake of leaving some works behind me when I am gone? But that is unnecessary, for my Outer Chapters and miscellaneous writings in two hundred volumes are quite enough to speak my mind to posterity. Moreover, in the Inner Chapters there are no rhetorical flourishes but mere plain outspoken words. I am also aware of the fact that the treatment of such matters will be looked upon by people of the world as being far-fetched. It is not comparable in the winning of popular appreciation to a treatment of the tangible affairs of the vulgar world. The reason why I do not refrain from writing on the subject, knowing that it will not be accorded proper reception by the

world, is that I am sure of good results and of the truthfulness of my teachers.

5. On account of the poor facilities for communication in the land, and of my poverty, misfortune, and lack of means, I have not secured the necessary medicines for the compounding. Yet here I am telling people that I know how to make gold and silver while I myself remain poverty-stricken. Is this not like the case of a man who sells medicines for curing lameness while he himself cannot walk? How can people be expected to be convinced? However, such arguments are not infallible, and we may grant exceptions in certain cases. I work hard at weaving in black and white simply for the sake of interesting curious and truth-loving scholars of the future in the study of the *Tao*.

6. The art of transformation is indeed omnipotent. People's persons are ordinarily observable, yet there are means for their concealment. Ghosts and spirits are not usually to be seen, yet they may be caused to appear. Many are those who cannot execute such performances.

7. Water and fire, which are in the sky, may be gotten by means of the *Yang Shui* (12883, 10416) (a light-concentrator of a copper alloy). *Ch'ien* (1733) (lead), which is white, can be reddened into *Tan* (red, redness, medicine). *Tan*, which is red, can be whitened into *Ch'ien*. Clouds, rain, frost, and snow, which are ethereal-essences of the sky, can be exactly duplicated from medicines.

8. The flying, the running, and the crawling beings are all of definite forms. Yet all of a sudden they may discard their original forms and be changed into other things. Man is the noblest of all creations; yet cases are not a few wherein he is transformed into a crane, a stone, a tiger, a monkey, a turtle, or even into sand. As to the formation of abysses from high mountains and the making of peaks out of deep valleys—such are but changes of the great earth. Transformation is inherent in the nature of heaven and earth. Why then should we think that gold and silver cannot be made from other things? For, are the fire obtained by the *Yang Shui* and the water gotten from the *Fang Chu* (3435, 2571) (a shelled creature) any different from ordinary fire and water? Dragons formed from snakes and grease made from *Mao Ts'an* (7689, ——) (a kind of vegetable growth) are no different from natural dragons and grease. The causes of all these lie in the responsive inspiration and incorporation of the spirit of creation. One cannot know the ends of such transformations unless he has thoroughly comprehended the reason and

nature of things. Nor can he tell of the phenomena unless he can trace matters to their beginnings and ends.

9. Narrow-minded and ignorant people take the profound to be uncouth, and relegate marvels to the realm of fiction. To these people, anything that has not been spoken of by *Chou Kung* (2450, 6568) or Confucius, or is not to be found in the Classics, is untrue. Is this not narrow-mindedness and ignorance?

10. People of the world think that the *Tao* does not exist just because *Liu Hsiang* (7270, 4283) did not succeed in attaining it. One may as well maintain, because of a crop failure from drought or from flood, that no harvest is possible from the cultivation of cereals.

11. Magistrate *Wu Ta Wên* (12748, 10470, 12633) of *Ch'êng Tu* (762, 12050), a learned and cultivated man, related that as disciple of *Li Kên* (6884, 5974), the *Tao-shih* (Seeker of the Way, Man of the Art), he saw him heating a mixture of *Ch'ien* (lead) and *Hsi* (4157) (tin). To this was added a big pea-size quantity of medicine. Upon stirring with an iron ladle and cooling, silver was obtained. Having gotten the secret formula, *Wu Ta Wên* attempted the compounding himself. However, being an official in active service, he could not perform the one hundred day dieting and purification necessary for his success—and so ended in failure. And so he exclaimed that this world was not worth living in!

12. *Huan Chün Shan* (5075, 3269, 9663) relates the following: *Ch'êng Wei* (757, 12528) of the *Han* dynasty had a liking for the art of the Yellow and White. He married a lady from a *Tao-shih* family. Once *Wei* was commanded to serve his sovereign as a retainer on a trip. However he lacked appropriate attire for the occasion and was therefore deeply grieved. Thereupon his wife came to his help by uttering the incantation, "Pray send forth two measures of silk." Forthwith appeared the desired fabric.

13. One day *Wei* was attempting the compounding of the medicine according to the *Chên Chung Hung Pao* (630, 2875, 5269, 8720) (The Great Treasure in the Pillow-Chest), a formula-book of *Huai-nan-tzŭ* (5034, 8128, 12317), and was without success when his wife approached him and found him fanning a fire under a pot of quicksilver. She said, "Let me try my hand at it." With these words she sprinkled into the pot a small quantity of some medicine from a wallet. After a short while, silver was obtained. Highly astounded *Wei* demanded of his wife why hadn't she enlightened him on the *Tao*. She replied that the *Tao* was to be attained only by those who are especially blessed. Failing in his attempt to extract the desired information

from his wife at the price of luxurious food and clothing, he tried by the advice of a friend to force her to yield the secret under the whip. Still the obdurate wife held her own, declaring that the *Tao* was to be revealed only to the appropriate persons. If they were the proper persons, the *Tao* would be revealed to them by the accomplished even if they were absolute strangers. If they were not of the right kind, they would not obtain the secrets of the *Tao* from the accomplished even by inflicting the penalty of piecemeal dissection of his body. But *Wei* kept on with his coercion until his wife ran about in madness with her body covered with mud and finally died.

14. As an instance from recent times we may consider the case of *Hua Ling Ssŭ* (5005, 7199, 10271), a talented, learned, and well-informed scholar who had been skeptical about things not found in the classics. However he once came across a *Tao-shih* who professed to have knowledge of the method of the Yellow and the White. He asked the *Tao-shih* to make good his words by deeds, which were as follows: *Ch'ien* (lead) was treated in an iron vessel with a certain powdered medicine and silver was obtained. The silver was further treated with some other medicine and gold was made. *Hua* also learned from the *Tao-shih* the art of penetrating-sight. After less than a hundred days practice he was able while lying in bed to have a very clear view of the skies and the surroundings of his house as if there had been no intervening roof and walls. He was able to hold conversation with his dead concubine as if she were alive. He heard the deities, to whom he had paid homage, returning courtesy to him when his bed seemed to be astir with some noise. And so *Hua* exclaimed that there was no limit to the possibilities of things in this world. Things not recorded in the classics should not be arbitrarily dismissed as untrue. It was natural for *Hua* who had not learnt of the Art to be astonished by such things.

15. The conditions for compounding the Yellow and the White are similar to those for compounding the *Shên Tan* (Divine Medicine). More than a hundred days of dieting and purification are required. The formula-books should be thoroughly understood and then the suitable formulas should be chosen for execution. The compounding is beyond the vulgar, the uncleanly, and the untalented who aspire to magical proficiency. The methods should be learnt directly from the accomplished. The compounding should be done in clean places in mountainous recesses so as to keep vulgar fools in ignorance. *Liu Hsiang* tried the compounding in the palace with the help of courtiers. In that case the conditions of dieting, purification, and isolation were not fulfilled. How then could he be successful?

16. According to the *Huan T'an Hsin Ch'üan* (5075, 10681, 4574, 3183): During his premiership *Shih Hsin Chien* (9893, 4562, 1671) was supplied with officials, attendants, and slaves to facilitate his attempt at gold-making. He met with no success. The failure was ascribed to his own inability. Having no use for more money, the Empress did not care much about the compounding at first. But she became eager for it when told of its power of life extension. And so she made him a *Lang* (an official rank), allowed him to live in the north palace, and treated him as a special delegate. How could the divine medicine be prepared in a palace by persons so numerous, vulgar, and improper!

17. Even ordinary dyers at work avoid the sight of people lest their dyeings be spoiled. How much more fastidious must we be while performing the art of the Yellow and the White!

18. In doing things, be they small or great, it is necessary to get at the essentials. Otherwise, even such trivial things as the making of simple food can not be carried out with success—not to speak of greater things.

19. Once I queried *Chêng Chün* saying, "*Lao Chün* has put forth the maxim that no high value ought to be placed on precious things which are difficult to obtain. Now in time of peace and plenty gold is allowed to waste in the mountains and jades in the valleys. Why then should sages of old so value gold and silver as to leave behind them formulas for their making?" To this *Chêng Chün* replied, "*Lao Chün* was referring on the one hand to those who in their desperate effort to obtain gold to gratify their pleasure of appreciation and wasteful decoration and even to attain longevity would scan sands, break stones, tear down mountains, dry up deep waters, defy long distances and precipices and drowning, and go to other excesses to the detriment of people's useful work, and on the other hand to those profiteering businessmen who in their hot pursuit of wealth for the indulgence of their senses would do away with the virtues of faithfulness and fair play and risk their lives over waters and precipices. It is another story with the *Chên Jen* (Men of Truth, Men Proficient in the Art, Sages). For they make gold with the purpose, not of getting rich, but of becoming *Hsien* by eating it. Therefore it is written in the Book, 'Gold can be made wherewith people can be raised above this worldly life.' Silver may be eaten for similar ends but is not as effective as gold."

20. Then I asked further, "Why should we not eat the gold and silver which are already in existence instead of taking the trouble to make them? What are made will not be real gold and silver but just make-believes."

21. Said *Chêng Chün* in reply, "The gold and silver which are found in the world are suitable for the purpose. But *Tao-shih* are all poor; witness the adage that *Hsien* are never stout and *Tao-shih* never rich. *Tao-shih* usually go in groups of five or ten, counting the teacher and his disciples. Poor as they are, how can they be expected to get the necessary gold and silver? Furthermore they cannot cover the great distances to gather the gold and silver which occur in nature. The only thing left for them to do is to make the metals themselves.

22. "In that they are the essences of the medicines, the gold and silver made are superior to those found in nature.

23. "Says the *Hsien Ching* (Book of Immortals); The refined spirit of *Tan* changes into gold. This is the theory of the formation of gold from *Tan*. This is why gold is usually to be found underneath where *Tan* occurs.

24. "The gold obtained by successful compounding is uniform inside and out. It may be put through a hundred workings without suffering any change. Therefore it was written in the formulas for its making that it may be made into nails. That shows its strength. Such results come of responsive infusion of the *Tao* of nature. Why should such deeds be called make-believes?

25. "Make-believes should be like the besmearing of iron with *Tsêng Ch'ing* whereby the metal takes on a reddish sheen simulating copper, and the action of egg-white on silver to obtain a yellow coloring resembling gold. In all these cases there are merely external changes but no internal transmutations.

26. "The fungus *Chih* (1788) (Plant of Longevity) is a natural growth. But according to the *Hsien Ching* it may be cultivated by means of the five stones and the five plants. The resulting plant will be exactly like that found in nature in the power of giving long life when eaten. The case is similar to the making of gold. The *Ch'ên* (656) (shellfish, clam) resulting from the transformation of the *Chih* (1870) (the ringed pheasant) and the *Ko* (6058) (a frog, also bivalves of various kinds) from fowls are no different from those found in nature.

27. "Therefore the *Hsien Ching* says, 'When the flowing pearl is going through the nine turns the father does not speak to the son. They come into harmonious relations when the Yellow and the White are obtained.' And, 'Those *Tao-shih* are great who attain the state of *Hsien* through the eating of the gold obtained from *Chu Sha* (2544, 9620) (Red Sand). They are the middle class who attain immortality by eating the *Chih* and by proper direction of the movement of the

Ch'i (ethereal essence) in their bodies. They are the inferiors who attain long lives of a thousand years or less through eating vegetable and plant matter.' Again, 'It is in the nature of things that gold and silver can be made. It is within the ability of people to learn to attain immortality.'"

28. The *Yü Tieh Chi* (13630, 11122, 923) (The Jade Tablet Records) says, "All the people in this wide, wide world are potentialities for making into immortals. Failure comes from hesitation. The gold obtained by the condensation of silver may be made into nails."

29. The *T'ung Chu Ching* (12285, 2533, 2122) (The Copper Pillar Book) says, "*Tan Sha* can be made into gold. *Ho Ch'ê* (3936, 574) (River Chariot) can be made into silver. The making can be done readily and the resulting substances are real. Once an adept in the Art a person will be able to become a *Hsien*."

30. *Huang-shan-tzŭ* (5124, 9663, 12317) says, "There is gold in nature. But that I can make too. Two Yellow and one Red, an unmistakable certainty."

31. Say the inscriptions on the Tortoise Shells, "My life is within my own control and not heaven's. The gold obtained from the Returned Medicine will bring about a long life of thousands upon thousands of years."

32. Certainly the ancients cannot be telling us untruths when they agree so well.

33. *Jung Yen* (a red or black salt?) and *Lu Yen* (niter or potash?) which are such cheap things in time of peace are now unobtainable at any price whatever. *Chiang Li* (1264, 6870) and *Shih Tan* (9964, 10629) cannot be obtained even at a price of thousands of cash per pound. Under such conditions those who know the methods are just as badly off as those who do not. What a deplorable situation!

34. Those who know the methods are usually too poor to get the means of compounding. Rich people do not know the processes. They may not believe in the Art if they happen to know of it. Granting a fair degree of faith, they will not usually part with any portion of their great accumulation of gold and silver to buy the necessary medicines for the compounding—for such action would be like releasing birds already in the cage in chase of those flying at large. Even if they are sure of profit in the enterprise, the hardships to be endured in dieting and in purification of the body will still be too much for them.

35. It is not wise to make attempts at compounding without learning the methods directly from famous teachers. Ordinary

medical recipes are obviously simple. Yet secrecy is thrown over the efficacious recipes which are in common use. In those formulas there appear such names of substances as *Hou Kung Yu Nü, P'i Tsê Chih Chiao, Fêng Chün Ni Wan, Mu Kuei Tzŭ, Chin Shang Chih, Fei Chün Ken, Fu Lung Kan, Pai Ma Han, Fu Yün Tzŭ, Lung Tzŭ Tan I, Yeh Kuang Ku, Pai Hua Li*, and *Tung Tsou Tsai*. The substances referred to are commonplaces which nevertheless cannot be identified without knowledge of the code concerned. Similar considerations obtain even to a much more intensified degree in the Art of the Yellow and the White.

36. Those who are adepts in the Art keep it a secret not merely because of its high value. Once the *Tao* is attained, immediately there comes immortality which is the highest achievement of the *Tao*. That is why it was so highly esteemed by the ancients.

37. The medicines mentioned in the formula-books may be common medicines under different disguise. For instance, *Hô Shang Chai Nü* (3936, 9729, ——, 8419) (Maiden on the River) (Mercury?) has no reference to a woman, nor *Ling Yang Tzŭ Ming* (7228, 12883, 12317, 7946) to a man, nor *Yü Yü Liang* (13618, 13615, 7016) (Remnants of the Rations of Emperor *Yü*) to rice, nor *Yao Chiang* (12907, 1210) (Fluid of Emperor *Yao*) to water.

38. People usually misinterpret formulas, mistaking *Lung Tan* (7479, 10629) (Dragon's Gall), *Hu Chang* (4920, 421) (Tiger's Palms), *Chi T'o* (810, 11441) (Chicken's Head), *Ya Chê* (12826, ——) (Duck's Feet), *Ma T'i* (7576, 11016) (Horse's Hoofs), *Ch'üan Hsüeh* (3192, 4847) (Dog's Blood), *Shu Wei* (10072, 12601) (Rat's Tail), and *Niu Hsi* (8346, 4140) (Ox's Knees) for animal substances, mistaking *Ch'üeh Pei* (3250, 8782) (Broken Cup), *Fu P'ên* (3723, 8850) (Inverted Basin), *Fu Li* (3739, ——) (Axes), *Ta Chi* (10470, 928) (Big Lance), *Kuei Chien* (6430, 1617) (Ghost's Arrows), and *T'ien Ko* (11208, 6148) (Sky Hooks) for iron and earthenware, and misinterpreting *Hu Wang Shih Chê* (4930, 12493, 9896, 542) (Delegate from the King of the Tartars), *I Ku Hsin Fu* (5355, 6209, 4574, 3749) (Bride-leaning-on-the-mother-in-law), *Yeh Wên Jên* (12989, 12633, 5624) (Rural Literati), *Shou T'ien Kung* (10012, 11236, 6568) (Old Man in Charge of a Field), *Tai Wên Yü* (10567, 12633, 13638), and *Hsü Ch'ang Ch'ing* (4748, 450, 2198) as the names of persons. Even common plants are sometimes not recognizable. Who can be expected to understand the mysterious formulas? It is not surprising that *Liu Hsiang* did not succeed in obtaining gold. When the essence of the Art is apprehended, no great talent will be needed but mere

common people will be successful in making the medicine. *Liu Hsiang* was no mere common person; he failed simply because he did not know how to decipher the code of names.

39. Some concise and effective formulas are given below for the benefit of fellow aspirants of the future. Five pounds or more of *Wu Tu Hsiung Huang* (12744, 12050, 4699, 5124), which is red as a cock's comb, lustrous, and free from admixed stone, is powdered, mixed with *Niu Tan* (8346, 10629) (Ox's Gall) and heated to dryness. The bottom of a one-bushel red-earthen pot is covered alternately, first with a three-tenths inch layer of powdered *Jung Yen* and *Shih Tan* (Stone Gall), then a half-inch layer of the powdered *Hsiung Huang*, and then another layer of *Jung Yen* and *Shih Tan*, and so on until all of the material has been exhausted. On top of this a two-inch layer of date-stone-sized pieces of burning charcoal is placed. Another pot is then inverted over it. The two pots are covered and sealed with mud over the entire outside, until the mud is three inches thick, to insure freedom from leakage. After drying in the shade for a month, the sealed vessels are heated with horse manure for three days and nights. After cooling, the vessels are opened, and the copper is pounded out which will flow like molten copper and iron. The copper is then cast into hollow cylinders, into which *Tan Sha Shui* (10618, 9620, 10128) (Medicine Sand Water) is put. After heating with horse manure for thirty day, gold is obtained. The gold is cast into hollow cylinders into which *Tan Sha* is put. After heating with horse manure for thirty days, the contents are taken out. Upon powdering a mixture of two parts of this with one of raw *Tan Sha* (Red Sand, Medicine Sand, Cinnabar)—mercury is quicksilver—coagulation immediately occurs into gold which is lustrous and beautifully colored and is fit for making nails.

40. Method of Making *Tan Sha Shui.* To a pound of *Tan Sha* in a raw bamboo pipe, two ounces of *Shih Tan* and two of *Hsiao Shih* (4297, 9964) (niter?) are added. The ends are then covered and sealed with *Ku Wan* (6234, 12490) (Bone Pills). When the sealings have become dry, the sealed pipe is placed in good bitter wine and buried three feet below the surface of the earth. In thirty days time a red water of bitter taste is obtained.

41. According to the *Tso Huang Chin Fa* (11741, 5124, 2032, 3366) (Method of Gold Making) received by *Chin Lo Hsien Shêng* (2032, 7343, 4440, 9865) from *Ch'ing-lin-tzŭ* (2184, 7157, 12317), tin sheets, each measuring six inches square by one and two-tenths inches thick, are covered with a one-tenth inch layer of a mud-like mixture

of *Ch'ih Yen* (Red Salt) and *Hui Chih* (5155, 1789) (potash-water, lime-water), ten pounds of tin to every four of *Ch'ih Yen.* They are then placed in a red-earthen pot and properly sealed. After heating for thirty days with horse manure, all the tin becomes ash-like and interspersed with bean-like pieces which are the yellow gold. The gold may also be obtained by ten refinings by the action of burning charcoal. Twenty ounces of gold are obtained from every twenty pounds of tin used. Only the earthen pots of *Ch'ang Sha* (450, 9624), *Kuei Yang* (6435, 12883), *Yü Chang* (13678, 390), and *Nan Hai* (8128, 3767) are effective for the compounding. Such pots are abundant in those places since they are made there for use in cooking.

42. Method of Making *Ch'ih Yen* (Red Salt). One pound each of *Han Shui Shih* (3825, 10128, 9964) (Cold Water Stone), *Han Yü Li* (3825, 13617, 6879), and *Pai Fan* (White Alum) are prepared. These, together with one pound of *Han Yen* (3825, 13112) (Cold Salt), are heated in an iron vessel by means of charcoal, when reduction to a red color occurs. The material is ready to use.

43. The Method of Gold Making as taught to *Lu Li Hsien Shêng* (——, 6870, 4440, 9865) by *Chi-ch'iu-tzŭ* is as follows: Two measures of *Fan Shih Shui* (Alum Water) are placed in an iron vessel and heated to boiling with charcoal. Some mercury is then added and stirred thoroughly until it has undergone six or seven boilings. Upon pouring the material on the ground, silver is obtained.

44. One measure of *Tan Sha Shui*, one of *Tsêng Ch'ing Shui* (11735, 2184, 10128), and two of *Hsiung Huang Shui* (Male Yellow Water, arsenic sulfide water?) are gently heated to boiling in a *Li* (——) vessel. After thorough stirring and further heating to boiling, some of the silver obtained above is added. Heating is continued until the mixture has undergone six or seven boilings. Upon pouring on the ground, the substance *Shang Sê Tzŭ Mo Chin* (9729, 9602, 12329, 7974, 2032) (Best Color Purple Mill Gold) is obtained.

45. Method of Making *Hsiung Huang Shui*. A mixture of one pound of *Hsiung Huang* and two ounces of *Hsiao Shih* is placed in a bamboo pipe. The ends are covered, sealed with *Ch'i Ku Wan* (1023, 6234, 12490) (Lacquer Bone Pills), and placed in good strong vinegar (or in good bitter wine according to some versions). After burial, two feet below the surface of the earth, for thirty days, *Hsiung Huang Shui* is obtained.

46. *Tsêng Ch'ing Shui* and *Fan Shih Shui* are made in the same manner, the only difference being in the contents of the bamboo pipe.

47. The Children's Method of Making Gold. A large iron cylinder, one foot and two inches both in diameter and in height, and a small iron cylinder, six inches in diameter, are used. One pound of good powdered *Ch'ih Shih Chih* (talc?), one of *Hsiao Shih* (niter?), one of *Yün Mu* (13812, 8067) (Mica?), one-half of *Liu Huang* (Sulfur), four ounces of *K'ung Ch'ing* (6595, 2184) (a blue copper compound?), and one of *Ning Shui Shih* (8339, 10128, 9964) (a mica like mineral) are intimately ground together and passed through fine-meshed sieves. The paste obtained by mixing with vinegar is used to make a lining two-tenths of an inch thick on the inside of the small cylinder.

48. A mixture of one pound of mercury, one-half of *Tan Sha*, and one-half of *Liang Fei* (7017, 3459) is stirred thoroughly until the mercury has disappeared. It is then placed in the small cylinder, overlaid with *Yün Mu*, and covered with an iron lid. The *Liang Fei* is obtained as follows: To ten pounds of *Ch'ien* (lead) heated in an open iron pot over a furnace three ounces of mercury are added. The portion which comes out during the early stages of the operation is scooped off with an iron ladle and is called *Liang Fei*.

49. Molten lead is introduced into the large iron cylinder on a stove. The small cylinder with its contents is then placed in the large cylinder, its top one half-inch below that of the large one. Heat is applied to keep the lead molten. Strong heating is continued for three days and nights, when *Tzŭ Fên* (12329, 3519) (Purple Powder) will be obtained.

50. Silver is obtained by heating together mercury and *Tzŭ Fên* until they have attained very close relations and then pouring the material into water.

51. Method of *Wu-Ch'êng-tzŭ*. In this method an iron vessel nine inches long and five inches in diameter is used. Its insides are lined with a paste made of a mixture of three pounds of ground *Hsiung Huang* and an equal quantity of the soil of earthworms and ants until the inside diameter of the vessel becomes three inches and the indented opening four inches. Two measures of *Tan Sha Shui* are added. The vessel with its contents is then placed over a fire of horse manure until exceedingly dry.

52. The dried material is next placed in a copper vessel, tightly covered with a copper lid built over with yellow sand and earthworm-soil to prevent leakage, and this is placed in a furnace containing a three-inch layer of charcoal until its mouth becomes reddened. Upon cooling all of the *Hsiung Huang* is found to have adhered to the copper vessel. This process is repeated with the remaining dry material

until it is exhausted. It will then be found that three pounds of the spirit of *Hsiung Huang* has separated and adhered to the vessel.

53. The substance thus obtained may be mixed with an equal quantity of yellow sand to be made into furnaces of various sizes for use in gold making. One of these furnaces is heated to redness in a charcoal fire. Mercury is added. When the mercury begins to stir, lead is poured in. Yellowness is then observed to start and spread from all sides toward the middle. Upon pouring on the ground, gold is obtained. The usefulness of the furnaces will be exhausted after they have served for the making of one thousand and five hundred pounds of medicine.

54. Upon treatment with *Mu Ching* (8089, 2157) wood and *Ch'ih Hsü Chiu* (1967, 10070, 2260) (a kind of alcoholic liquor) for a hundred days, the gold softens and becomes kneadable. The eating of one pound of this medicine in pills of the size of small beans, one pill at a time, three times a day, will kill off all the three worms and drive away all the hundred diseases. If the eater be a blind man, he will see; if a deaf man, he will hear; and if an old person, he will be rejuvenated to the state of thirty years of age. The eater will not be scorched by fire and will be invulnerable to all evils, poisons, bleak winds, and excessive heat and dampness.

55. The ingestion of three pounds will enable a person to walk on the surface of water. The hundred spirits of the mountains and waters will come to wait on him. He will live as long as heaven and earth.

56. By rubbing the eyes with a pill boiled in *Chu Hsüeh* (2611, 4847) (Blood-like Sap of the *Chu* Plant) and *Chu Ts'ao* (Red Plant), one will be able to see ghosts and things under the ground and to write in the dark.

57. When a pill that is painted with the blood of a white goat is thrown into water, fishes and dragons will come forth to be caught.

58. A pill painted with the blood of a black goat, when hung over the gateway of a village, will protect the entire village from epidemics. If it is smeared on the foreheads of cattle, sheep, or any of the six domestic animals, they will be protected against diseases and against tigers and leopards.

59. When a pill painted with tiger's spleen and snake's fat is dropped into an enemy's camp at the beginning of a month, the hostile forces will be thrown into confusion, fighting among themselves.

60. A pill is painted with an ox's blood. Throw it into a well, and the water will boil. Throw it into a flowing stream, and the water will reverse its course for a distance of a hundred steps.

61. When a pill that has been painted with a white dog's blood is put in a dark place in a community temple, the ghosts of the temple will come forth ready to serve.

62. Let a pill be painted with hare's blood. Put it in a dark place and fairies numbering sixty or seventy will be at one's service.

63. On putting a pill painted with *Li Yü Tan* (6883, 13510, (10629) (the carp's gall) into water, the water will go asunder making a gap of ten feet for breathing space. The carrying of such a pill will prevent one's clothes from being wetted in the rain.

64. By swallowing a pill that has been boiled with *Tzŭ Hsien* (12329, 4541) one will be free from hunger for a hundred days.

65. By carrying in one's hair a pill that has been boiled with *Tz'ŭ Shih* (12406, 9964) one will be invulnerable in fighting against outlaws. All missiles directed at him will be reversed.

66. Compound *Liu Ting* (7276, 11253), *Liu Jên* (7276, 5610), and *Shang T'u* (9729, 12099) into a pill. When it is placed between the nose and the upper lip one's person will vanish from view. Spit a pill at a fire in a northerly direction and the fire will die out. Throw a pill at a tree in a westerly direction at the *Shên Yu* (9816, 13398) hours on *Kêng Hsin* days and the tree will wither on the very day. With cautious steps one may come up to tigers, wolves, snakes, and venomous snakes to kill them immediately by throwing a pill at each.

67. Inks prepared from such pills will penetrate stone, gold, and wood. The indentations will be too deep to be erased.

68. A person who has been dead for not more than a day may be revived by washing a pill down his throat and spraying his face with water of *Yüeh Chien Shang* (13768, 1592, 9729).

69. By putting in his fingernail a pill that has been painted with wolf's and crane's blood, one can bring about changes in things by pointing his fingers at them and at the same time uttering verbal orders. The movement of mountains and trees may be apparent to everybody when as a matter of fact no motion occurs.

70. As in the case of the making of the nine medicines, services of worship should be properly performed to *T'ai I* (Supreme Monad), *Hsüan Nü*, and *Lao-tzŭ* in the making of the Yellow and the White. There should be constant burning of the five incenses. When gold is successfully compounded, three pounds of it should first be thrown into deep water and ten pounds of it in a marketplace before any of it is used for other purposes.

ABSTRACT AND TABLE OF CONTENTS

CHAPTER IV. ON THE GOLD MEDICINE

1. Thousands of books agree that *Huan Tan* (Returned Medicine) and *Chin I* (Gold Fluid) are the means of becoming *Hsien*.

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4. The pretentiousness of the ignorant.

5. How *Pao-p'u-tzŭ* received knowledge of the art—from *Chêng Chün* who received it from *Pao-p'u-tzŭ's* great uncle, *Hsien Kung*, who received it from *Tso Yüan-Fang* who received it from a spiritual being.

6. *Chin Tan* (Gold Medicine) compared with medicines of less efficacy. Gold Fluid and Returned Medicine recommended by *Lao-tzŭ*.

7. The effect of the two medicines, a result of deriving strength from an external substance.

8. For the few who believe in the *Tao*, practical directions for the practice of the art are given.

9. The improved state of mind which comes from learning the art.

10. The futility of working with poor materials.

11. More depends upon the degree of working than upon the particular recipe.

12. Even a minor medicine is far superior to vegetable substances. Vegetable substances, unlike *Tan Sha*, turn to ashes when they are burned.

13. Many do not even know that mercury comes out of *Tan Sha*.

14. The *Chên Jên* of antiquity transmitted a sure method of attaining immortality.

15. *Pao-p'u-tzŭ* has always attached a high value to the truth and to unusal information.

16. The present writing is for the truly appreciative ones of later times.

17. People of the world fritter away their time and energy.

18. Wealthy people also are superficial.

19. The prize is worth the trial.

20. Popular judgement of the *Tao* cannot be trusted.

21. *Huang Ti* gained immortality by means of the medicine. Vegetable medicines and deep breathing confer long life, but *Shên Tan* confers immortality.

22. *Huang Ti* transmitted the book to *Hsüan-tzŭ*, giving him advice on the pursuit of the *Tao*.

23. Conditions which ought to be observed in preparing the medicine. Vegetable materials are not suitable.

24. The nine preparations are unknown to unfortunate millions.

25. Certain ceremonies of worship are also requisite.

26. The first medicine, *Tan Hua.* Directions for its preparation. It confers immortality in seven days and converts quicksilver into gold.

27. The second medicine, *Shên Tan* or *Shên Fu,* confers immortality in a hundred days and has other magical powers.

28. The third medicine, *Shên Tan,* confers immortality in a hundred days and has other magical powers.

29. The fourth medicine, *Huan Tan,* confers immortality in a hundred days, converts quicksilver to gold, and has other magical powers.

30. The fifth medicine, *Êrh Tan,* confers immortality in thirty days and has other magical powers.

31. The sixth medicine, *Lien Tan,* confers immortality in ten days and converts quicksilver into gold.

32. The seventh medicine, *Jou Tan,* confers immortality in a hundred days, restores the reproductive faculty, and converts lead (?) into gold.

33. The eighth medicine, *Fu Tan,* confers immortality on the day that it is eaten, and wards off evil.

34. The ninth medicine, *Han Tan,* confers immortality in a hundred days and has other magical powers.

35. Any one of the nine medicines is sufficient to make the eater a *Hsien.*

36. There is also the *T'ai Ch'ing Shên Tan* which originated with *Yüan Chün,* teacher of *Lao-tzŭ.* The last three chapters of the *T'ai Ch'ing Kuan T'ien Ching* treat of the medicine.

37. Even *Yüan Chün* acquired his great powers by following the *Tao* and by eating the medicine.

38. Warning against disclosing the secrets of the *Tao.*

39. When the medicine has been made, a sacrificial offering of a hundred catties should be made.

40. Directions for making the offering.

41. *Shên Tan* is alone necessary for immortality.

42. *Hsin Yeh Yin Chün* succeeded in making the *T'ai Ch'ing Tan* and became an immortal by means of it.

43. The *T'ai Ch'ing Tan* is more difficult to prepare than the Nine Furnace-pot Medicine. Its special powers, and the method of its preparation.

44. The more "turns," the more powerful the medicine. The

word which is here translated "turns" evidently signifies some repeatable process, like sublimation or distillation, by which the medicine is rendered purer and more potent.

45. The medicine of the ninth turn, sublimed with *Chu Êrh* by the heat of the sun, yields a Returned Medicine which will raise the user to the skies in broad daylight.

46. The efficacy depends upon the number of the turns.

47. *Chiu Kuang Tan.* Method of preparation. Five turns of five different colors.

48. *Ch'ing Tan*, the Blue Medicine, raises the dead.

49. Magical power of the Black Medicine.

50. Magical Power of the Yellow Medicine.

51. The materials needful for the preparation of the medicine by the method of the *Wu Ling Tan Ching* are enumerated. The medicine has the power to bring about immortality but is not as efficacious as those made according to the already described Supreme Clear Method and Nine Furnace-pot Method.

52. The *Min Shan* method of *Chang Kai Ta* described. The medicine restores sight, hair, teeth, etc., and by repeated eating confers immortality.

53. *Wu-ch'êng-tzŭ's* medicine; its preparation.

54. *Hsien-mên-tzŭ's* medicine; its preparation and magical effects. One attains the *Tao* by eating it regularly for three consecutive years.

55. The *Li Ch'êng Tan;* its preparation and effects; its use in conjunction with the Red Herb.

56. The *Ch'ü Fu Tan*, made from *Tan* fishes, imparts certain magical powers.

57. Preparation of the medicine according to *Ch'ih-sung-tzŭ.* It imparts redness to the features and hair, and confers immortality.

58. Preparation of *Shih Hsien Shêng's* medicine; it contains animal ingredients and confers long life.

59. Preparation of the medicine of *K'ang-fêng-tzŭ;* it contains animal ingredients and confers long life.

60. *Ts'ui-wên-tzŭ's* medicine; its preparation described. It extends life and confers immortality.

61. The method of *Liu Yüan.* One tenth of a quart of the medicine enables one to live a thousand years, habitual drinking of it brings immortality.

62. Description of *Lo-ch'ang-tzŭ's* procedure. The medicine makes a *Hsien* in three years.

63. *Li Wên's* preparation described; it makes a *Hsien* in a year.

64. *Yin-tzŭ's* preparation described; it confers long life.

65. Preparation of the *T'ai I Chao P'o Tan;* it revives the dead.

66. *Ts'ai Nü Tan,* made from *Tan* and animal products, gives the user the services of two fairies.

67. *Chi-ch'iu-tzŭ's* preparation described; it confers long life.

68. *Mo-tzŭ's* preparation described; it confers immortality.

69. Method of preparing *Chang Tzŭ Ho Tan,* a medicine which brings long life.

70. Preparation of the elixir of *Ch'i Li.*

71. *Ch'i Li* medicine converts lead into silver and *Hsiung Huang* into gold.

72. *Yü Kuei Tan;* its preparation and effects.

73. Preparation of *Chou Hou Tan;* it confers immortality and converts copper into gold.

74. Preparation of *Li Kung's* medicine; it will enable a man to last as long as the sky and the earth.

75. Preparation of *Liu Shêng's* medicine; it imparts long life and restores youth.

76. Preparation of *Wang Chün's* medicine; it prevents ageing and decay of the body.

77. Preparation of *Ch'ên Shêng's* medicine; it protects from hunger and confers long life.

78. Preparation of the medicine of *Han Chung Chung;* it prolongs life, improves the eyesight, etc.

79. *Chin I* (Gold Fluid) is as efficacious as the nine medicines. *Lao-tzŭ* transmitted the secret of it to *Yüan Chün.* The process, which occupies one hundred days, should be carried out in private. The effects of the medicine in making *Hsien.* Desirability of abstinence from cereals.

80. A medicine prepared from Gold Fluid and quicksilver makes a *Hsien* out of any person. It converts mercury into silver, and has other marvelous properties. By eating and drinking out of vessels made of this medicine, one will attain immortality. Gold Fluid converts yellow earth into serviceable yellow gold.

81. This gold, again heated, yields a medicine which will make one an earthly immortal and will convert mercury into silver, and this silver will further convert lead into silver. Method of procuring the classic on the Gold Fluid. The classic must not be given indiscreetly.

82. The nine medicines are best but the materials are not easy to

procure and the process is difficult. The compounding of the Gold Fluid is much easier. A total expenditure of 400,000 cash will make a quantity of it large enough to transform eight persons into *Hsien*. Large amounts of material are necessary for successful operation.

83. There is also the *Êrh Huang Chin* (Food of Yellow Gold) which is not as good as Yellow Gold but is far better than other medicines. Several methods of refining gold.

84. An inferior medicine, which brings immortality only through frequent ingestion, may be made from silver and large pearls of the oyster.

85. Not only money but isolation in a celebrated mountain is necessary for success in compounding the Gold Fluid and the nine medicines. The secret must not be printed in books on the *Tao*.

86. The compounder of the medicine must guard against ridicule, must make offerings to the gods, must work in a secluded place in a famous mountain, and should diet, refraining from stimulant food and raw fish, from one hundred days before beginning the work until the medicine is done.

87. The seeker should not work in a small mountain, but in a famous one, and should guard against devils, chickens, dogs, children, and women.

88. A list of twenty-seven mountains recommended by the Book of the Immortals.

89. A list of six large islands which are next in order as places good for the preparation of the medicine.

90. Eight accessible mountains in the central part of the country.

91. *Pao-p'u-tzŭ* explains his position in seeking the *Tao* and in writing about it.

92. Formula of the Lesser Divine Medicine which brings rejuvenation and immortality.

93. Method of the Lesser Medicine which will cure the hundred sicknesses and dispel the three demons, confer immortality and impart magical properties.

94. Method of the Lesser Food of Yellow Gold. The medicine, made from gold (or silver) and wine confers magical powers and makes a man an immortal of the earth.

95. Method of the Food of Reduced Yellow Gold of *Liang-i-tzŭ*. The medicine, made from hog's skin and fat, bitter wine, and gold, confers longevity and immortality. The secret should not be divulged, else the medicine cannot be prepared successfully.

ABSTRACT AND TABLE OF CONTENTS

CHAPTER XVI. ON THE YELLOW AND THE WHITE

1. The writings on the art of transmutation. They are difficult to understand and are not believed by the common people.

2. *Pao-p'u-tzŭ* received three books from *Chêng Chün*.

3. *Chêng Chün* claimed that he had accomplished a successful transmutation with *Tso Chün*. The same diligence and hardships are necessary as in the compounding of the Gold Medicine.

4. The author explains his position in writing on these matters. In the Inner Chapters there are no rhetorical flourishes but mere plain outspoken words. He is sure of good results and of the truthfulness of his teachers.

5. Although he has not made gold and silver himself, he writes simply for the sake of interesting truth-loving scholars of the future in the study of the *Tao*.

6. Strange things can be accomplished, but there are many who cannot accomplish them.

7. Several strange things. Lead, which is white, can be reddened into *Tan*, and *Tan*, which is red, can be whitened into lead, etc.

8. Transformations are common in nature—why not into gold and silver? But they are difficult to understand unless matters are traced to their beginnings and ends.

9. Narrow-minded and ignorant people are incredulous.

10. The fact that *Liu Hsiang* did not attain the *Tao* does not prove that it is unattainable.

11. *Wu Ta Wên* reported that *Li Kên* converted a mixture of lead and tin into silver but was unable himself to repeat the process with success because he could not fulfil the conditions.

12. The wife of *Ch'êng Wei* by an incantation summoned forth two measures of silk.

13. A story from the *Chên Chung Hung Pao* (The Great Treasure in the Pillow-Chest) of *Huai-nan-tzŭ* (a work which is not now known to exist). The wife of *Wei* converted mercury into silver, but suffered severe punishment and finally death rather than reveal the secret to her husband whom she considered unworthy.

14. *Hua Ling Ssŭ* in recent times witnessed the conversion of lead into silver and of the silver into gold. From a *Tao-shih* he learned the art of penetrating-sight.

15. The conditions for compounding the Yellow and the White are similar to those for compounding the *Shên Tan*. *Liu Hsiang* was unable to accomplish it in a palace.

16. *Shih Hsin Chien* was of course unable to carry out the operation successfully in a palace surrounded by attendants and slaves.

17. The seeker must be more fastidious than ordinary dyers who avoid the sight of people lest their dyeings be spoiled.

18. The seeker must get at the essentials.

19. Report of the author's conversation with *Chêng Chün*. The *Chên Jên* make gold for the purpose of becoming *Hsien* by eating it. Silver may be eaten for the same purpose but is not as good as gold.

20. The author asks him why natural gold and silver may not be eaten for the same purpose, and suggests that the gold and silver which are made may be make-believes.

21. *Chêng Chün* replies that ordinary gold and silver are suitable but *Tao-shih* are poor and have no choice except to make the metals for themselves.

22. The superiority of the gold and silver which are made.

23. Theory of the formation of gold from *Tan*.

24. The gold obtained by successful compounding is uniform throughout; it may be worked without change and may be made into nails. Why should it be called make-believe?

25. Examples of make-believe: reddening of iron by means of a copper salt, tarnishing of silver by means of egg-white to give it the appearance of gold—merely external changes.

26. Like the making of gold is the cultivation of the fungus, *Chih*, etc. The cultivated plant is exactly like that found in nature.

27. A quotation from the Book of Immortals. Three classes of *Hsien*, the highest is attained by eating gold made from *Chu Sha* (Red Sand). The making of gold and silver and the attaining of immortality are natural processes.

28. A quotation from the Jade Tablet Records in confirmation of these opinions.

29. Quotation from the Copper Pillar Book. Materials for making gold and silver, the authenticity of the products.

30. Quotation from *Huang-shan-tzŭ*.

31. Quotation from the Tortoise Shell Inscriptions.

32. The unanimity of the ancients indicates their truthfulness.

33. The present prices of reagents are deplorably high.

34. Rich people are unwilling to risk their wealth on the process and to undergo the hardships which are necessary.

35. It is unwise to make attempts without learning the methods first from famous teachers. Ordinary medical recipes are difficult because of the secret names. Examples. The art of the Yellow and the White is much more difficult for the same reason.

36. Immortality is the highest achievement of the *Tao.*

37. Common medicines are designated in the formula-books by unfamiliar names. Examples.

38. Further examples, names which are easily misunderstood or readily misinterpreted. *Liu Hsiang* failed because he did not know how to decipher the code of names.

39. Description of apparatus and process for procuring copper, for converting this into gold, and for converting *Tan Sha* into gold.

40. Method of making *Tan Sha Shui.*

41. Method, derived form *Ch'ing-lin-tzŭ,* of converting tin into gold, a method which possibly yields stannic sulfide or "mosaic gold." Process described in considerable detail.

42. Method of making *Ch'ih Yen.*

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44. Preparation of Best Color Purple Mill Gold from this silver.

45. Method of making *Hsiung Huang Shui.*

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47–50. The Children's Method of making gold. Apparatus described. *Liang Fei,* prepared from lead and mercury, is converted into *Tzŭ Fen* (Purple Powder) by heating with mercury and *Tan Sha,* and this with more mercury yields silver.

51–53. Method of *Wu-ch'êng-tzŭ.* Apparatus described. Gold from mercury and lead by the action of the spirit of *Hsiung Huang.* The furnaces are exhausted after having served for the making of 1500 pounds of medicine.

54. Kneadable gold. The effect of the pills after one pound has been taken.

55. Effect of the ingestion of three pounds.

56–65. Magical effects of various preparations of the pill.

66. Preparation of another pill which confers invisibility and has other magical powers.

67. Ineradicable ink.

68. Reviving the dead.

69. Magical control over natural objects, which control however is only apparent.

70. In making the Yellow and the White, services of worship are necessary (*c. f.* IV, 86). The five incenses should be burned constantly. When the gold is successfully compounded, three pounds of it should first be thrown into deep water (*c. f.* IV, 22) and ten pounds of it in a marketplace (*c. f.* IV, 40) before any of it is used for other purposes.

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Proceedings of the American Academy of Arts and Sciences

Vol. 70, No. 7—December, 1935

COMPRESSIBILITIES AND ELECTRICAL RESISTANCE UNDER PRESSURE, WITH SPECIAL REFERENCE TO INTERMETALLIC COMPOUNDS

By P. W. Bridgman

Investigations on Light and Heat made or published with aid from the Rumford Fund.

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Received October 15, 1935 Presented October 9, 1935

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INTRODUCTION

The so-called intermetallic compounds are an interesting class of substance, the properties of which are beginning to be amenable to theoretical treatment. It therefore seemed worth while to determine the effect of hydrostatic pressure on a number of representative compounds. The following results were obtained during the last few years for the compressibility and change of resistance under pressure at 30° and 75° with my conventional pressure apparatus up to 12000 kg/cm^2. With one exception, all of the "intermetallic compounds" here studied crystallize in the cubic system; it is hardly worth while to measure the physical constants of substances crystallizing in other systems unless single crystals are used and the properties determined in different directions. Up to the present it has been found possible to produce single crystals of these substances in very few cases, so that the number of them which may be advantageously measured is at present somewhat restricted. Furthermore, only those compounds have been studied here whose crystal structure is adequately known; results for such substances should be of greater theoretical significance than for substances with incompletely determined structure. In addition to the intermetallic compounds, a few other substances have been measured since my last publication on the subject, and these are collected here. It is probable that this paper marks, at least for the present, the close of routine determinations of resistance and compressibility to 12000; a large number of substances have now been measured, and other experiments over a considerably wider pressure range may now be undertaken more profitably.

Occasion will also be taken in this paper to give corrected values for a few of my earliest compressibilities. In the course of a recent extension to 20000 kg/cm^2 of measurements of the compressibility of the alkali metals, I found that there had been an error in the earliest results to 12000; this error was in the reduction of change of length to change of volume, the correction term having been applied with the wrong sign. The magnitude of this error increases with the magnitude of the change of volume; it is greatest for the most compressible substances and at the highest pressures, and the initial compressibilities are not at all affected by it. This error slightly affects the compressibility of iron, which has been used as fundamental in all my compressibility determinations. All results published since 1925 strictly should be corrected for the new value of iron, but the change is so small that it is hardly worth considering. The new values for iron are used in the calculations of this paper, and will be used in the future.

During the measurements of this paper a source of error developed in the "lever piezometer" which had not been previously recognized. The error was first encountered in measuring the compressibility of LiF, and consisted in a number of rather regular discontinuities in the length, change of length plotted against pressure presenting an appearance much like that of a flight of steps. The effects were perfectly reproducible, and were without hysteresis. I thought at first I had hold of some new quantum phenomenon, and a great deal of time was spent in making measurements with differently prepared specimens, and with two different piezometers. The explanation turned out at last to be instrumental, but for a while I was forced to suppose that the phenomenon was real because of a series of hardly credible coincidences, since there was apparently a correlation with the purity, the effect was repeated with a second piezometer, and also it repeated when the length of the specimen was altered, thus employing a different part of the slide wires. The effect was found to be due to wear of the cross wire on which the wire connected to the potentiometer slider. A flat place worn on the cross wire, combined with an almost infinitesimal periodic structure in the sliding wire, like a "wash-board" dirt road, which also may have been the result of wear, was the adequate explanation. The effect was at once eliminated by providing a new cross wire, and the effect can be eliminated in the future by so mounting the cross wire that it can be rotated to avoid wear. It is, of course, disturbing to think that this source of error may have been present in some results already published, in particular in connection with some of the anomalies reported. It is possible that a few of these results may have been slightly affected, but in most cases, not. This instrumental error can be recognized by being without hysteresis, and it was a progressive development which rapidly become worse toward the climax with LiF. After discovering it, I found it necessary to repeat measurements which had been made on several substances just before the effect was recognized and not yet published, but this is, I think, as far back as errors of any importance extend. Further details with regard to already published results will be given in the discussion.

Proper preparation of the intermetallic compounds is important, and was done by a special technique, except in those cases where I was fortunate enough to obtain the compounds ready made. In this connection I am much indebted not only to several industrial research laboratories, which will be mentioned in detail later, but also to Dr. R. F. Mehl, who interested himself in the problem of obtaining some of these compounds, and through whom I was able to make several important contacts.

The pure component metals were usually finely divided by a new file, weighed proportions were mixed together, and introduced into the chamber A of the fused quartz arrangement shown in Figure 1. The whole was highly evacuated with gentle heating, and then fused off after argon under a pressure of a few millimeters had been admitted. The whole was then placed horizontally in an electric furnace kept at a temperature perhaps 50° C above the melting point of the compound, as determined from the published phase diagram, until it was completely melted. The liquid was homogenized by violent shaking.

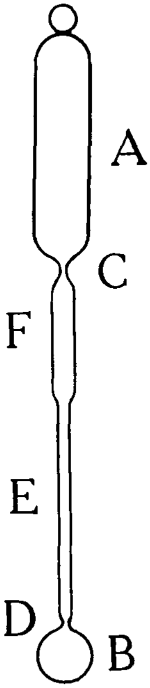

FIGURE 1. The quartz vessel for casting the intermetallic compounds.

The furnace was next rotated rapidly into a vertical position, and the quartz lowered by a wire attached to the ring at the upper end into a dish of cold water placed immediately below the mouth of the furnace. The reduction of pressure when the bulb B strikes the water forces the liquid alloy through the constriction C, which serves as a filter, into the compartments E and F, which are filled completely, the alloy freezing at the second constriction D. The proportions of the quartz apparatus and the initial argon pressure must be right in order that the action shall take place as described, but the correct values are not difficult to find. The solidified compound was next subjected to an annealing process by maintaining it at a temperature in the annealing range as near the melting temperature as the phase diagram suggested was safe, for a time which might run up to 10 days. By this method homogeneous specimens were prepared; the homogeneity was checked in many cases by determining the X-ray structure of small samples taken from either end of the specimen. The X-ray examination was made by Mr. C. Lanza, for whose assistance I am very much indebted. The diameter of the chamber F was about 3 mm, and that of E about 1 mm; F gave the compressibility sample, and E the resistance sample.

The detailed results now follow. First are given those compounds which crystallize in the so-called γ structure, with an atom-electron ratio of 13:21; second the compounds with β structure and an atom-electron ratio of 2:3; third, a more or less miscellaneous assortment of other intermetallic compounds, and fourth other types of substance.

DETAILED RESULTS

Ag_5Cd_8. The compressibility was measured of a single sample, in the annealed condition. There was consistent hysteresis between the readings with increasing and decreasing pressure, the extreme width of the loop being about 3% of the maximum effect at 30° and 3.6% at 75°. The average deviation of a single reading from a smooth curve passing through the center of the loop was 1.0% at 30° and 1.2% at 75°; considerably smaller deviations would of course have been obtained if the deviations had been calculated from the respective branches of the loop. The results are:

$$\text{At } 30°,\ -\Delta V/V_0 = 12.36 \times 10^{-7}p - 2.76 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 12.66 \times 10^{-7}p - 2.73 \times 10^{-12}p^2,$$

p in kg/cm².

The second degree terms in these expressions are the same as for pure iron.

The electrical resistance was measured as a function of pressure in the unannealed condition at 30°, and on the same sample, after annealing, at both 30° and 75°. The results are unusual, both in the unannealed and annealed condition in that when resistance is plotted against pressure two straight lines are obtained, with a distinct break in direction. This phenomenon was established only with increasing pressure, when a great many more readings than usual were taken, for example, 20 readings on one occasion instead of the usual 7 with increasing pressure. There can be no doubt but that the straight line reproduces the measurements much better than the customary second degree expression. A smaller number of readings was taken with decreasing pressure; there was the same sort of hysteresis as shown by the compressibility measurements, and again two straight lines reproduces the results better than a second degree curve. The results were:

Unannealed. 30°. Break at 5730 kg/cm^2, where the resistance is 0.9813 of its initial value. In terms of the resistance at the break the pressure coefficient below the break is -3.27×10^{-6}, and above the break -2.57×10^{-6}. The specific resistance at 30° is 1.30×10^{-5} ohm cm.

Annealed. 30°. Break at 5950 kg/cm^2, where the resistance is 0.9816 of its initial value. In terms of the resistance at the break the coefficient below the break is -3.14×10^{-6}, and above the break -2.08×10^{-6}.

75°. Break at 5950, where the resistance is 0.9774 of its initial value. In terms of the resistance at the break the pressure coefficient below the break is -3.87×10^{-6} and above the break -2.83×10^{-6}.

The specific resistance at 30° is 1.306×10^{-5} ohm cm. The average temperature coefficient of resistance between 0° and 100° at atmospheric pressure, obtained by linear extrapolation of the readings at 30° and 75° is 0.00248.

Except for the value of the pressure coefficient beyond the break the annealing appears to produce very little effect.

Ag_5Zn_8. Both compressibility and resistance samples were annealed for 7 days at 600° C and quenched. Two sets of compressibility measurements were made, before and after the modification of the cross wire. The first runs showed a small step at 75° but none at 30°. The second runs gave no break. There was, however, considerable hysteresis on both sets of runs; the width of the loop of the second run was 1.3% of the total effect at 30°, and 2.1% at 75°. The following results represent the mean with increasing and decreasing pressure:

$$\text{At } 30°,\ -\Delta V/V_0 = 11.14 \times 10^{-7}p - 4.62 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 11.60 \times 10^{-7}p - 4.98 \times 10^{-12}p^2.$$

The total compression at 12000 obtained with the first set-up was 0.3% greater than the above at 30° and 2.2% less at 75°.

The mean linear thermal expansion between 30° and 75° at atmospheric pressure was 0.000022.

The effect of pressure on resistance was very small absolutely, but in the range of variation the effects were very irregular. At 30° the effect of pressure is very definitely to decrease resistance, but there is hysteresis, and on standing at 6000 kg for 15 hours there was creep in the direction of increasing resistance amounting to one half the total effect of 12000. At 75° the creep is also unmistakably present, but it is not so important, and there is also pronounced hysteresis. The following are only rough average results:

$$\text{At } 30°, \quad \Delta R/R(0, 30°) = -4.0 \times 10^{-7}p$$

$$\text{At } 75°, \quad \Delta R/R(0, 75°) = +10.4 \times 10^{-7}p.$$

The specific resistance at atmospheric pressure at 30° C was 21.5×10^{-6}. A rough value for the mean temperature coefficient between 0° and 100° is 0.00245.

Cu_5Cd_8. Measurements of the compressibility of this compound have already been published.[1] There were the most complicated small scale fluctuations, which it was difficult to believe could be characteristic of the material itself. The results were therefore repeated with a new sample, which had been annealed at a mean temperature of 485° C for 10 days. The data for this second sample still showed irregularities, but not nearly as striking as those of the first. The irregularities were of a somewhat different character, there now being rather pronounced hysteresis, evidence of some sort of not perfectly reversible internal change produced by the action of pressure. Measurements were made only at 30° C. The average deviation of a single reading from the smooth curve drawn through the center of the hysteresis loop was 1.1% of the maximum effect. The results were as follows:

$$\text{At } 30°, -\Delta V/V_0 = 16.3 \times 10^{-7}p - 27 \times 10^{-12}p^2.$$

The resistance sample was annealed in the same way as the second compressibility sample. The results were very much smoother than for the compressibility. At 30° the average deviation of a single reading from a smooth curve was 0.11% of the maximum effect, and at 75° 0.09%. The effect of pressure on resistance can be represented by the following expression:

$$\text{At } 30°, \quad \Delta R/R(0, 30°) = -1.096 \times 10^{-5}p + 1.245 \times 10^{-9}p^2$$

$$\text{At } 75°, \quad \Delta R/R(0, 75°) = -1.138 \times 10^{-5}p + 1.362 \times 10^{-9}p^2.$$

The specific resistance at atmospheric pressure at 30° was 17.25 × 10^{-6}, and the mean temperature coefficient between 0° and 100°, 0.00383. The latter is thus as high as that of some of the pure metals.

Cu_5Zn_8. Measurements were made on two different samples; on No. 1 two sets of measurements were made, before and after the modification of the cross wire of the piezometer. Only one set of measurements was made on No. 2, after the modification. No. 1 was cast from above 900° C and annealed between 685° and 720° for 13 days. Both samples were X-rayed, and seemed to be homogeneous. The first set-up with No. 1 showed various irregularities, but these entirely disappeared with the modified apparatus, and the effect was doubtless instrumental. The second set-up showed hysteresis of about 0.2% at both temperatures; the regularity of the points was therefore somewhat better than usual for these intermetallic compounds. The results from the second set-up with No. 1 were:

$$\text{At } 30°,\ -\Delta V/V_0 = 10.07 \times 10^{-7}p - 4.77 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 10.39 \times 10^{-7}p - 5.82 \times 10^{-12}p^2.$$

The first set-up gave a smaller result at 30° and a larger one at 75°.

The mean linear thermal expansion at atmospheric pressure was 0.000020.

Sample No. 2, which had been prepared two years before No. 1, was measured only once, after the piezometer had been rectified. At 30° there was noticeable irregularity and hysteresis, but nothing remarkable. At 75°, on the other hand, there was a very marked break at 8000 kg/cm², with a discontinuity in relative length of 0.00032. Above and below this the points lay regularly. The results were as follows, at 75° smoothing across the break:

$$\text{At } 30°,\ -\Delta V/V_0 = 12.35 \times 10^{-7}p - 24.0 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 9.51 \times 10^{-7}p - 1.9 \times 10^{-12}p^2.$$

No. 2 thus seems to be entirely different from No. 1. The compressibility of No. 2 at 75° beyond the break is very nearly the same as that of No 1, so that here we may be concerned with corresponding phases. But the much larger compressibility of No. 2 at 30° and its smaller compressibility at 75° below the break points to a complicated system of different phases.

The mean linear thermal expansion of No. 2 was 0.000018.

Resistance measurements were made only on No. 1. The measurements at 30° were smooth, but there was a very small continual drift during the readings, so that after the run the resistance was 0.02% (or 1.4% of the pressure effect) smaller than initially. At 75° the creep was much larger, there being a permanent change of resistance after the run of 0.16%. Except for creep, the points with increasing and decreasing pressure were very regular, lying on smooth curves with an average deviation of 0.08% of the maximum pressure effect. The following are the mean results for increasing and decreasing pressure:

$$\text{At } 30°,\ \Delta R/R(0, 30°) = -1.477 \times 10^{-7}p + 1.06 \times 10^{-11}p^2$$

$$\text{At } 75°,\ \Delta R/R(0, 75°) = -1.612 \times 10^{-7}p + 1.04 \times 10^{-11}p^2.$$

At atmospheric pressure the specific resistance at 30° was 10.68×10^{-6} ohm cm. The mean temperature coefficient between 0° and 100° was 0.00256. Again, the shifting electrical resistance points to internal complications.

$Cu_{31}Sn_8$. Measurements were made on four different samples. The method of preparation was approximately the same for all: they were cast from above 800° and annealed at 550° for 10 days and then quenched. Compressibility measurements on No. 1 and No. 2 were made with the original piezometer sometime before the irregularities due to wear of the cross wire had begun to develop, so that it is safe to accept these results. These first two samples agreed in showing rather large hysteresis, the character of which was very much like that of Cu_5Zn_8. However the absolute magnitudes of the compressibilities of the first two samples differed by amounts far beyond any possible experimental error, that of the second sample being 22.5% less than that of the first. The measurements were accordingly repeated considerably later with a third sample; this showed the step-like structure due to wear of the cross wire, and the results were accordingly discarded. The mean, however, should be significant, and this agreed much more nearly with No. 2 than with No. 1. After the piezometer had been rectified, measurements were made with No. 4. These were the most regular of all, showing no hysteresis, and with scattering of the individual points no greater than normal for these intermetallic compounds. The width of the hysteresis loop of No. 2 at 30° was 8.3% of the maximum pressure effect, and the width at 75° was 9.3%. The hysteresis of No. 1 was much like this. The following results were found:

$$\text{No. 1. At } 30°,\ -\Delta V/V_0 = 11.40 \times 10^{-7}p - 11.8 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 10.98 \times 10^{-7}p - 5.7 \times 10^{-12}p^2.$$

$$\text{No. 2.}\quad \text{At } 30^\circ,\ -\Delta V/V_0 = 8.83 \times 10^{-7}p - 5.3 \times 10^{-12}p^2$$

$$\text{At } 75^\circ,\ -\Delta V/V_0 = 9.29 \times 10^{-7}p - 7.3 \times 10^{-12}p^2.$$

$$\text{No. 4.}\quad \text{At } 30^\circ,\ -\Delta V/V_0 = 9.85 \times 10^{-7}p - 6.03 \times 10^{-12}p^2$$

$$\text{At } 75^\circ,\ -\Delta V/V_0 = 10.18 \times 10^{-7}p - 6.15 \times 10^{-12}p^2.$$

At 30°, the initial compressibility of No. 3, ignoring the break, was 8.5×10^{-7}.

The compressibilities of the various samples are seen to vary by an amount far beyond possible experimental error; it would appear to be intrinsic in the material.

At atmospheric pressure the mean linear thermal expansion of No. 1 was 0.000019; of No. 2, 0.000021; of No. 3, 0.000018; and of No. 4, 0.000019. Nos. 1 and 4 thus have the same expansion, but the compressibilities are markedly different.

The resistance under pressure was measured for two different samples from the same meltings as compressibility samples Nos. 1 and 2 respectively. The electrical properties were very much more concordant than the compressibilities. The average deviation from a smooth curve of a single reading for No. 1 was 0.3% at 30° and 0.06% at 75° (one discard at 75°). The corresponding figures for No. 2 were 0.16% and 0.10% (two discards). The results were:

$$\text{No. 1.}\quad \text{At } 30^\circ,\ \Delta R/R(0, 30^\circ) = -1.057 \times 10^{-7}p + 7.3 \times 10^{-12}p^2$$

$$\text{At } 75^\circ,\ \Delta R/R(0, 75^\circ) = -1.087 \times 10^{-7}p + 7.8 \times 10^{-12}p^2.$$

At atmospheric pressure the specific resistance at 30° was 51.6×10^{-6} ohm cm, and the mean temperature coefficient between 0° and 100°, 0.00060.

$$\text{No. 2.}\quad \text{At } 30^\circ,\ \Delta R/R(0, 30^\circ) = -1.055 \times 10^{-7}p + 4.4 \times 10^{-12}p^2$$

$$\text{At } 75^\circ,\ \Delta R/R(0, 75^\circ) = -1.068 \times 10^{-7}p + 4.4 \times 10^{-12}p^2.$$

At atmospheric pressure the specific resistance at 30° was 49.4×10^{-6} ohm cm, and the mean temperature coefficient between 0° and 100°, 0.00063_5.

CuZn. The material was prepared by casting from 930° C, annealing at 570° to 600° for 5 days, and then quenching. Hysteresis was found, and was abnormally large; the width of the loop at 30° was 8.5% of the maximum effect, and at 75°, 21%. The points lay smoothly on each branch of the hysteresis loop, with an average deviation of the order of one tenth of the width of the loop. The mean results, obtained by drawing a smooth curve through the center of the loop, were:

$$\text{At } 30°, \ -\Delta V/V_0 = 8.95 \times 10^{-7}p - 2.5_2 \times 10^{-12}p^2$$

$$\text{At } 75°, \ -\Delta V/V_0 = 9.20 \times 10^{-7}p - 2.4_6 \times 10^{-12}p^2.$$

The mean linear expansion at atmospheric pressure was 0.000020. In spite of the pressure hysteresis, the hysteresis with temperature at atmospheric pressure was very much less than usual.

The electrical resistance measurements at 30° showed a slight creep, the resistance decreasing by 0.08% after subjection to pressure. The mean deviation of a single reading from a smooth curve was 0.95% of the maximum pressure effect. At 75° the permanent alteration of resistance after application of 12000 was considerably larger, 0.45%, and the points with increasing and decreasing pressure lay on quite distinct curves. The points with decreasing pressure lay much more smoothly, and only these were used in calculating the final results. The mean deviation of these points from a smooth curve was imperceptible. The results were:

$$\text{At } 30°, \ \Delta R/R(0, 30°) = -2.18 \times 10^{-6}p + 1.2 \times 10^{-11}p^2$$

$$\text{At } 75°, \ \Delta R/R(0, 75°) = -2.11 \times 10^{-6}p + 0.8 \times 10^{-11}p^2.$$

At atmospheric pressure the specific resistance at 30° was 6.04 × 10^{-6} ohm cm, and the mean temperature coefficient between 0° and 100° 0.00334.

AgCd. This was cast from above 760° C, annealed for 13 days at a mean temperature of 620° C, and quenched.

Two compressibility set-ups were used. The first showed a step-like structure, which completely disappeared on repetition with the rectified piezometer. Only the second results were accepted. The width of the hysteresis loop was 1.5% of the total effect at 30° and 1.7% at 75°. The following results are the mean with increasing and decreasing pressure:

$$\text{At } 30°, \ -\Delta V/V_0 = 11.54 \times 10^{-7}p - 4.6 \times 10^{-12}p^2$$

$$\text{At } 75°, \ -\Delta V/V_0 = 11.91 \times 10^{-7}p - 4.7 \times 10^{-12}p^2.$$

The mean linear thermal expansion at atmospheric pressure was 0.000020.

The resistance showed the same sort of permanent change after application of pressure as did CuZn, but the effect at 75° was not nearly so prominent, and the mean curve was used at both temperatures. At 30° the permanent change of zero was 0.08% of the total resistance, and at 75°, 0.04%. The average deviation from a smooth curve of a single reading was 0.9% of the maximum effect at 30°, and 1.5% at 75°. The results were:

$$\text{At } 30°,\ \Delta R/R(0, 30°) = -1.776 \times 10^{-6}p + 1.62 \times 10^{-11}p^2$$

$$\text{At } 75°,\ \Delta R/R(0, 75°) = -1.926 \times 10^{-6}p + 2.19 \times 10^{-11}p^2.$$

At atmospheric pressure the specific resistance at 30° was 6.62 × 10^{-6} ohm cm, and the mean temperature coefficient between 0° and 100° 0.00174.

AuZn. Measurements were made on both unannealed and annealed samples. As far as the compressibility results go, annealing was only partially successful in reducing hysteresis and other irregularities. At both temperatures there was marked hysteresis, the points with increasing and decreasing pressure lying smoothly on two branches of a hysteresis loop. The width of the loop for the unannealed sample was 5.3% at 30° and 10.2% at 75°. The corresponding figures for the annealed sample were 3.6% at 30° and 2.8% at 75°. The results are: Unannealed,

$$\text{At } 30°,\ -\Delta V/V_0 = 7.24 \times 10^{-7}p - 2.4 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 7.42 \times 10^{-7}p - 2.4 \times 10^{-12}p^2.$$

The mean linear thermal expansion at atmospheric pressure was 0.000020.

Annealed,

$$\text{At } 30°,\ -\Delta V/V_0 = 7.47 \times 10^{-7}p - 2.4 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 7.87 \times 10^{-7}p - 2.4 \times 10^{-12}p^2.$$

Mean expansion, 0.000020.

The electrical resistance measurements did not show the hysteresis that the compressibility measurements did, except paradoxically at 75° the annealed sample showed a loop with width 1.1% of the maximum effect. The mean departure of a single reading from smooth curves for the unannealed specimen was 0.11% at 30° and 0.18% at 75°. The corresponding figures for the annealed sample were 0.12% and 0.45%. The results were:

Unannealed,

$$\text{At } 30°,\ \Delta R/R(0, 30°) = -3.51 \times 10^{-6}p + 1.82 \times 10^{-11}p^2$$

$$\text{At } 75°,\ \Delta R/R(0, 75°) = -3.44 \times 10^{-6}p + 1.34 \times 10^{-11}p^2.$$

Within experimental error the second degree expression is not quite adequate to reproduce the results; the initial rate of decrease is a little more rapid than given by the formula, and the final rate a little less. The maximum discrepancy is 2 or 3 tenths of a percent of the maximum pressure effect.

At atmospheric pressure the specific resistance at 30° was 7.89×10^{-6} ohm cm; the average temperature coefficient between 0° and 100° was 0.00333.

Annealed:

$$\text{At } 30°,\ \Delta R/R(0, 30°) = -3.53 \times 10^{-7}p + 1.71 \times 10^{-11}p^2$$

$$\text{At } 75°,\ \Delta R/R(0, 75°) = -3.51 \times 10^{-7}p + 1.74 \times 10^{-11}p^2.$$

At atmospheric pressure the specific resistance at 30° was 7.95×10^{-6} ohm cm; the average temperature coefficient between 0° and 100° was 0.00333.

AgZn. This was cast from 800°, annealed at an average temperature of 595° C for 9 days, and quenched.

Three different set-ups were used with the same compressibility sample. The first, before rectification of the piezometer, gave a sharp change of direction at 30° at 9000 kg/cm^2, and at 75° gave a discontinuity of length of relative amount 0.0004 between 1000 and 3000. The run at 75° was repeated with the length of the sample altered so as to bring the readings on a quite different part of the slide wire. The break repeated itself, and therefore can be accepted as real. About seven and one half months later, after the piezometer had been repaired, the measurements were repeated. A break was again found at 75°, but at a higher pressure, between 7000 and 8000, and of relative magnitude 0.0003. At 30° a break of approximately the same magnitude now appeared at between 3000 and 4000, and the anomoly previously found at 9000 was still present at the same place, although somewhat altered in character. I believe that there can be no question of the reality of these effects. There is much evidence which indicates that these compounds may be the seat of slow time effects.

The mean results obtained with the final set-up, smoothing over the breaks, were:

$$\text{At } 30°,\ -\Delta V/V_0 = 10.30 \times 10^{-7}p - 1.9 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 10.26 \times 10^{-7}p - 1.8 \times 10^{-12}p^2.$$

The first set-up gave results somewhat less at 30° and somewhat higher at 75°. The mean linear thermal expansion at atmospheric pressure at the time of the first measurements was 0.000033, and at the time of the second 0.000025. The change again indicates some internal transformation.

The resistance did not show marked hysteresis. The average deviation of a single reading from a smooth curve was 0.54% at 30° and 0.20% at 75°. The results were:

$$\text{At } 30°,\ \Delta R/R(0, 30°) = -4.38 \times 10^{-6}p + 4.2 \times 10^{-11}p^2$$

$$\text{At } 75°,\ \Delta R/R(0, 75°) = -5.17 \times 10^{-6}p + 4.0 \times 10^{-11}p^2.$$

The magnitude of the variation with temperature is somewhat unusual.

At atmospheric pressure the specific resistance at 30° was $6._0 \times 10^{-6}$ ohm cm. This result is uncertain because of geometrical imperfections in the specimen; an upper limit for the resistance is 6.2×10^{-6}, which is thus very low. The average temperature coefficient between 0° and 100° was 0.00489, a value higher than that of either of the component pure metals.

Cu_5Sn. This was cast from 820° C, annealed at a mean temperature of 620° for 18 days, and quenched.

The first set-up for the compressibility, before the piezometer had been rectified, gave a characteristic step, which was doubtless instrumental. Repetition with the rectified apparatus gave no steps, but appreciable hysteresis. The width of the loop at 30° was 1.9% of the maximum effect, and 1.2% at 75°. The results were:

$$\text{At } 30°,\ -\Delta V/V_0 = 8.23 \times 10^{-7}p - 2.0 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 8.37 \times 10^{-7}p - 1.8 \times 10^{-12}p^2.$$

The mean results given by the first set-up, made seven and one half months before, smoothing over the break, were essentially the same, suggesting that there is little if any change in this compound with time.

The mean linear thermal expansion at atmospheric pressure was 0.000018.

The electrical resistance at 30° showed traces of hysteresis. At 75° there was slight creep in the direction of decreasing resistance, the zero being altered after exposure to 12000 kg/cm² by 5% of the maximum pressure effect. At 30° the average deviation of a single reading from a smooth curve was 0.25% of the maximum pressure effect, and at 75°, 0.47%. The results were:

$$\text{At } 30°,\ \Delta R/R(0, 30°) = -9.57 \times 10^{-7}p + 2.8 \times 10^{-12}p^2$$

$$\text{At } 75°,\ \Delta R/R(0, 75°) = -10.39 \times 10^{-7}p + 4.3 \times 10^{-12}p^2.$$

At atmospheric pressure the specific resistance at 30° was 27.5×10^{-6} ohm cm, and the average temperature coefficient between 0° and 100° 0.00075. The latter is unusually low, and of the same order as that of $Cu_{31}Sn_8$.

Ag_2Al. This material I owe to the kindness of Professor J. C. G. Wulff of M. I. T., who in turn obtained it from the Research Laboratory of the Aluminum Co. of America. Three set-ups were used and two samples in determining the compressibility. No. 1 was used as it came; No. 2 was cut from the same block as No. 1 and annealed in vacuum at 540° for 10 days. The two sets of compressibility measurements on No. 1 were made at intervals of fifteen months, before and after rectification of the piezometer. The first run, made a year before the trouble with the piezometer became noticeable, gave wide hysteresis and a superposed step-like structure at both 30° and 75°. The break at 30° occurred between 5000 and 6000, and in relative amount was 0.000055. At 75° a break occurred only with increasing pressure, between 3000 and 4000, and about twice as much in amount. On repetition with the rectified piezometer 15 months later the break at 30° had disappeared, but there was a break at 75° between 7000 and 8000, and 0.00008 in amount. This is the same phenomenon as that shown by AgZn, the pressure at which the break occurs increasing with time. This description would account for the disappearance of the break at 30°, which may simply have been displaced beyond 12000. The compressibility given by the second set-up was:

At 30°, $-\Delta V/V_0 = 10.39 \times 10^{-7}p - 5.3 \times 10^{-12}p^2$

At 75°, $-\Delta V/V_0 = 10.20 \times 10^{-7}p - 1.8 \times 10^{-12}p^2$, smoothing over the break.

The mean compressibility at 30° of the first set-up was almost exactly the same as above, but at 75° it was 7% higher.

The mean linear thermal expansion at atmospheric pressure of this sample was 0.000021.

The compressibility results on No. 2, which had been annealed for 10 days, were unexpectedly much more irregular than those on No. 1, with much greater scattering of the points. The mean results were:

$$\text{At } 30°, \; -\Delta V/V_0 = 10.13 \times 10^{-7}p - 5.7 \times 10^{-12}p^2$$

$$\text{At } 75°, \; -\Delta V/V_0 = 10.76 - 10^{-7}p - 8.7 \times 10^{-12}p^2.$$

The compressibility is thus not materially different from that of No. 1. The mean linear thermal expansion, however, was perceptibly different, 0.000019 instead of 0.000021.

The resistance results were so unusual on No. 1 that this led to the decision to try the effect of a long annealing. There was, however, no essential change in the qualitative behavior produced by annealing. At 30° resistance increases linearly with pressure. At 75° with increasing pressure resistance decreases nearly linearly except for a small initial rise between 0 and 2000 kg/cm², but on releasing pressure from 12000, the resistance at first continues to decrease until about 8000 is reached, where there is a minimum. Beyond this the resistance increases again with decreasing pressure until at atmospheric pressure in the case of No. 2 the initial zero was almost exactly recovered. The width of the hysteresis loop at 75° was equal to the total magnitude of the pressure effect at 12000. The following are rough results for No. 2:

At 30°, $\Delta R/R(0, 30°) = +10.1 \times 10^{-8}p.$

At 75°, the linear change with increasing pressure is given by

$$\Delta R/R(0, 75°) = -17.5 \times 10^{-8}p.$$

Both these figures were numerically less by about 30% for No. 1.

At atmospheric pressure the specific resistance at 30° of No. 2 was 29.7×10^{-6} ohm cm. The mean temperature coefficient of resistance between 0° and 100° varied from 0.00116 on the first increase of temperature to 0.00065 on the final decrease of temperature. The corresponding figures for No. 1 were the same within approximately 1%.

Mg_3Al_2. This alloy I owe to the courtesy of the Dow Chemical Co. The composition determined by quantitative analysis of the actual specimen was Al 42.3%, Mg 57.7%. The theoretical composition corresponding to Mg_3Al_2 is Al 42.6%, Mg 57.4%.

The compressibility measurements showed no hysteresis, but at 75° there was a slight permanent shortening after exposure to 12000 amounting to 1% of the maximum pressure effect. At 30° the average deviation of a single reading from a smooth curve was 0.15% of the maximum pressure effect, and at 75° 0.25%. The results were:

$$\text{At } 30°, -\Delta V/V_0 = 24.66 \times 10^{-7}p - 16.1 \times 10^{-12}p^2$$

$$\text{At } 75°, -\Delta V/V_0 = 24.65 \times 10^{-7}p - 11.6 \times 10^{-12}p^2$$

The mean linear thermal expansion at atmospheric pressure was 0.000020.

The effect of pressure on electrical resistance was very small indeed; there were fluctuations in the individual readings amounting to the entire pressure effect. There cannot be much doubt, however, as to the sign of the effect and its approximate magnitude.

$$\text{At } 30°,\ \Delta R/R(0, 30°) = +\,6.0 \times 10^{-9}$$
$$\text{At } 75°,\ \Delta R/R(0, 75°) = +\,1.8 \times 10^{-9}$$

At atmospheric pressure the specific resistance at 30° was 92.3×10^{-6} ohm cm, and the mean temperature coefficient between 0° and 100° 0.00146. Both these figures indicate a rather large departure from the state of a pure metal.

Mg_xAl_y. This compound I owe to the kindness of Professor J. C. G. Wulff of M. I. T. who obtained it from the Aluminum Co. of America. The composition as made up before melting was 50% by weight. According to the phase diagram in International Critical Tables this should be within the region of homogeneity of the phase with the structure of Mg_3Al_2, but Professor Wulff tells me that X-ray analysis failed to disclose evidence of this structure, and it is now not considered certain that such a compound as Mg_3Al_2 exists.

Both at 30° and 75° the compressibility measurements showed small permanent changes of length after exposure to 12000 of the order of 4% of the maximum pressure effect. The mean deviation from a smooth curve of a single reading at 30° was 0.60% of the maximum pressure effect, and at 75° 0.77%. The results were:

$$\text{At } 30°,\ -\Delta V/V_0 = 17.90 \times 10^{-7}p - 8.9 \times 10^{-12}p^2$$
$$\text{At } 75°,\ -\Delta V/V_0 = 19.14 \times 10^{-7}p - 14.0 \times 10^{-12}p^2.$$

At atmospheric pressure the mean linear thermal expansion was 0.000042, much larger than usual.

The specimen was too deeply fractured to permit any measurements of the resistance.

Mg_2Pb. This I owe to the courtesy of the Dow Chemical Co. It is unstable in air, and had to be kept and machined under oil.

The compressibility measurements showed an unsymmetrical hysteresis loop at both temperatures, the maximum width of the loop being at 3000 instead of the usual 6000. The maximum width was 2.7% of the maximum effect at 30° and 2.9% at 75°. The average deviation of a single reading from a smooth curve was 0.80% of the maximum effect at 30° and 0.71% at 75°. The results were:

$$\text{At } 30°,\ -\Delta V/V_0 = 26.13 \times 10^{-7}p - 21.2 \times 10^{-12}p^2$$
$$\text{At } 75°,\ -\Delta V/V_0 = 27.36 \times 10^{-7}p - 23.4 \times 10^{-12}p^2.$$

The mean linear thermal expansion at atmospheric pressure was 0.000021_5.

The material was not good enough to give samples suitable for resistance measurements.

$MgZn_2$. This crystallizes in the hexagonal rather than the cubic system, but as a sample was available through the courtesy of the Dow Chemical Co. it seemed worth while to measure it. The crystal structure seemed to be of small grain size, so that these results should be fairly representative of the average of different directions in the crystal. The readings did not show noticeable hysteresis, but the irregularities were greater than usual, probably a result of the unequal compressibility of the different grains in different directions. The average deviation from a smooth curve of a single reading was 0.32% of the maximum effect at 30°, .49% at 52.5°, and 0.42% at 75°. The results were:

$$\text{At } 30°,\ -\Delta V/V_0 = 16.57 \times 10^{-7}p - 6.1 \times 10^{-12}p^2$$

$$\text{At } 52.5°,\ -\Delta V/V_0 = 17.12 \times 10^{-7}p - 6.2 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 17.12 \times 10^{-7}p - 6.0 \times 10^{-12}p^2.$$

The mean linear thermal expansion at atmospheric pressure was 0.000025.

The resistance specimen showed a rather large permanent change of resistance on the initial seasoning application of pressure, but after that the readings were steady. The mean deviation from a smooth curve of a single reading at 30° was 2.9% of the maximum effect, and at 75° 2.0%. The results were:

$$\text{At } 30°,\ \Delta R/R(0, 30°) = -2.51 \times 10^{-6}p + 4.6 \times 10^{-11}p^2$$

$$\text{At } 75°,\ \Delta R/R(0, 75°) = -2.52 \times 10^{-6}p + 5.2 \times 10^{-11}p^2.$$

At atmospheric pressure the specific resistance at 30° was 25.6×10^{-6} ohm cm, and the mean temperature coefficient between 0° and 100° 0.00321.

SbSn. The crystal structure of this is of the simple NaCl type. The specimen was prepared in quartz in the usual way, and annealed at 300° for 9 days.

The compressibility measurements showed no marked hysteresis. At 30° the average deviation from a smooth curve of a single reading was 0.14% of the maximum effect, and at 75° 0.24%. The results were:

$$\text{At } 30°, -\Delta V/V_0 = 22.17 \times 10^{-7}p - 20.3 \times 10^{-12}p^2$$

$$\text{At } 75°, -\Delta V/V_0 = 22.50 \times 10^{-7}p - 18.3 \times 10^{-12}p^2.$$

The mean linear thermal expansion at atmospheric pressure was 0.000016.

The mean deviation from a smooth curve of a single one of the resistance measurements was 0.09% at 30° and 0.44% at 75°. The results differed so much from a second degree expansion that it is necessary to give them in Table I.

TABLE I

RESISTANCE OF SbSn

Pressure kg/cm^2	30° $-\Delta R/R(0, 30°)$	75° $-\Delta R/R(0, 75°)$
2000	.0274	.0281
4000	.0506	.0506
6000	.0718	.0715
8000	.0918	.0910
10000	.1110	.1097
12000	.1290	.1276

At atmospheric pressure the specific resistance at 30° was 28.4 10^{-6} ohm cm, and the mean temperature coefficient between 0° and 100° 0.00275.

AuSb$_2$. This crystallizes in the same system as FeS_2. It was prepared from the melt at 550°, and annealed at 400° for 13 days.

The compressibility results lay on open hysteresis loops, the maximum width of the loop at both 30° and 75° being 3.9% of the pressure effect. The results given below are the mean with increasing and decreasing pressure, obtained by drawing a smooth curve through the center of the loop. The mean deviation from a smooth curve of a single reading was 1.2% of the maximum effect at 30° and 1.6% at 75°. This deviation would have been much less if it had been calculated from the respective branch of the loop. The results were:

$$\text{At } 30°, -\Delta V/V_0 = 11.44 \times 10^{-7}p - 8.2 \times 10^{-12}p^2$$

$$\text{At } 75°, -\Delta V/V_0 = 11.69 \times 10^{-7}p - 9.4 \times 10^{-12}p^2.$$

At atmospheric pressure the mean linear thermal expansion was 0.000005_5, much smaller than for most of these compounds.

The resistance measurements gave readings which showed a mean deviation from a smooth curve of 0.22% of the maximum effect at 30° and 0.14% at 75° (one discard). The results were:

$$\text{At } 30°,\ \Delta R/R(0, 30°) = -2.87 \times 10^{-6}p + 6.5 \times 10^{-12}p^2$$

$$\text{At } 75°,\ \Delta R/R(0, 75°) = -2.90 \times 10^{-6}p + 6.4 \times 10^{-12}p^2.$$

At atmospheric pressure the specific resistance at 30° was 29.0×10^{-6}, and the mean temperature coefficient between 0° and 100° 0.00318.

Sb_2Tl_7. The crystal structure is not known, except that it is cubic with 6 molecules in the unit cell.

The compressibility measurements did not show the usual hysteresis, but there was perhaps more scattering than usual. At 30° the mean deviation of a single reading from a smooth curve was 0.25% of the maximum pressure effect, and at 75° 0.42%. The results were:

$$\text{At } 30°,\ -\Delta V/V_0 = 32.15 \times 10^{-7}p - 25.7 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 33.41 \times 10^{-7}p - 25.1 \times 10^{-12}p^2.$$

The mean linear thermal expansion at atmospheric pressure was 0.000031. Both expansion and compressibility are larger than usual.

The average deviation from a smooth curve of a single reading of the electrical resistance was 0.17% at 30° and 0.19% at 75°. The results were:

$$\text{At } 30°,\ \Delta R/R(0, 30°) = -\ 9.176 \times 10^{-6}p + 9.62 \times 10^{-11}p^2$$

$$\text{At } 75°,\ \Delta R/R(0, 75°) = -\ 9.330 \times 10^{-6}p + 10.57 \times 10^{-11}p^2.$$

At atmospheric pressure the specific resistance at 30° was 88.5×10^{-6}, and the average temperature coefficient between 0° and 100° −.000563. Both these figures are far from the values for pure metals.

This completes the list of intermetallic compounds. A number of other more or less miscellaneous substances were available, and seemed to be of sufficient interest to justify measurement.

Germanium. The compressibility of this element has already been measured;[2] the particular point now was to obtain the effect of pressure on resistance. However, it seemed worth while to repeat the compressibility measurements, since the previous measurements had been irregular, and soon after conclusion of the measurements the specimen had spontaneously fractured while resting under room conditions.

For the new material I am again indebted to Professor L. M. Dennis of Cornell University, by whom it had been highly purified. The sample was cast in quartz in much the same fashion as the intermetallic compounds.

Although the compressibility results for the new sample were more irregular than usual for pure metals, there were no such extreme effects as had been shown by the previous sample, and the new measurements are therefore doubtless to be preferred. At both 30° and 75° there were small permanent decreases of length after application of pressure, the change being of the order of 2.5% of the total decrease under 12000, or 0.00008 on the total length. At both temperatures the compressibility with decreasing pressure was taken as the better. The extreme deviation of a single reading from a smooth curve at decreasing pressure was 0.16% of the maximum effect at 30°, and 0.30% at 75°. The results were:

$$\text{At } 30°, \ -\Delta V/V_0 = 14.11 \times 10^{-7}p - 6.09 \times 10^{-12}p^2$$

$$\text{At } 75°, \ -\Delta V/V_0 = 14.39 \times 10^{-7}p - 6.96 \times 10^{-12}p^2$$

The new values of compressibility average 3.5% greater than the previous values; the difference is greater at 75°.

The mean linear thermal expansion at atmospheric pressure was 0.000007.

The resistance sample was in the form of a rod 1 mm in diameter and 9 mm between potential terminals. It was cast in quartz at the same time as the compressibility sample, and appeared to be a single crystal grain; since Germanium is cubic this introduced no indetermination into the results. The conventional potentiometer method of measuring resistance was used with two current and two potential terminals. The connections were made by spring clips; the contact resistance was high and irregular and during the measurements contact had to be continually restored by sparking at the contact with the current from a small magneto. Of course high contact resistance introduces no error into the measurements, but merely cuts down the galvanometer deflection and so the sensitivity. The measurements of resistance went perfectly smoothly; no single reading deviated from a smooth curve by more than 0.2% of the total effect. Germanium turns out to be one of the comparatively few elements the resistance of which increases with pressure. The increase cannot be reproduced by the usual second degree formula, and is accordingly given in Table II for pressure intervals of 2000 kg/cm^2.

TABLE II

RESISTENCE OF GERMANIUM

Pressure kg/cm²	30° $\Delta R/R(0, 30°)$	75° $\Delta R/R(0, 75°)$
2000	+.0261	+.0287
4000	.0566	.0610
6000	.0911	.0981
8000	.1297	.1434
10000	.1761	.1966
12000	.2283	.2608

The curve of resistance against pressure is convex toward the pressure axis; that is, the pressure effect becomes relatively greater as pressure increases. This is also the case for all other positive pressure coefficients that have been determined.

At atmospheric pressure the specific resistance at 30° was 0.01168 ohm cm. The mean temperature coefficient between 0° and 100°, calculated by linear extrapolation of readings at 30° and 75°, was 0.00140, much less than for the metallic elements. It is known that this temperature coefficient reverses sign at higher temperatures.

LiF. It has already been described how a great many measurements were made on this substance, all giving apparently some sort of step-like structure, but that eventually the trouble was located in the worn cross wire of the piezometer. The following results were obtained after the source of error had been eliminated by a change in design of the cross wire. The material was cut from a single crystal, which had been crystallized out of the melt in this laboratory by Dr. E. G. Schneider, who has had a great deal of experience in making single crystals of this material for the optical experiments of Dr. T. Lyman in the ultra violet. The material was without detectible chemical impurity.

The step-like structure entirely disappeared with the change in the cross wire, and the results were of customary smoothness. At 30° the average deviation of a single reading from a smooth curve was 0.2% of the maximum effect, and at 75° 0.4%. The results were:

$$\text{At } 30°,\ -\Delta V/V_0 = 14.95 \times 10^{-7}p - 6.78 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 15.64 \times 10^{-7}p - 6.96 \times 10^{-12}p^2.$$

Essentially the same results, except for the superposed steps, were obtained with five samples of highly purified material, four of these being different samples prepared by Dr. Schneider, and one a single crystal for which I am indebted to Professor D. C. Stockbarger of M. I. T. by whom it was prepared by a method not different in essential principle from that used by Dr. Schneider.

The compressibility of LiF has been previously measured in this laboratory by Slater[3] with my apparatus. At 30° his value for the first degree term is 15.0×10^{-7} against 14.95×10^{-7} found above, and for the second degree term 8.6×10^{-12} against 6.78×10^{-12} above. This agreement must be considered satisfactory, in view of the fact that Dr. Slater regarded his value for LiF as the most inaccurate of all his values, and had independently suggested to me the desirability of a redetermination when this single crystal material of high purity became available. However, the new value for the temperature coefficient of compressibility is about five fold greater than the value of Slater. There is a misprint in the value of Slater's compressibility as quoted by me,[4] which makes his value appear about 25% too low.

Ag_2S. This material is of interest because of the peculiar temperature dependence of resistance at atmospheric pressure; I thought that the behavior under pressure might also be unusual. The material, obtained from another research laboratory, was said to have been commercially pure Ag_2S. formed without binder by high pressure in a mold into a strongly coherent rectangular block. For the pressure measurements, pieces were cut from this block with a hack saw, and formed with a file or by turning.

The compressibility sample was subjected to two seasoning applications of pressure, one to 12000 and one to 13000, but in spite of this there were still permanent changes of length after the compressibility measurements. At 75° the permanent shortening after the compressibility measurements to 12000 was 10% of the maximum pressure effect, and at 30° 4%. The following compressibility is the mean of results obtained with increasing and decreasing pressure. The points with increasing or decreasing pressure separately lay on smooth curves with about the customary deviation, of the order of 0.1 or 0.2%. The results were:

$$\text{At } 30°,\ -\Delta V/V_0 = 32.06 \times 10^{-7}p - 49.1 \times 10^{-12}p^2$$

$$\text{At } 75°,\ -\Delta V/V_0 = 30.31 \times 10^{-7}p - 38.9 \times 10^{-12}p^2.$$

The very distinctly smaller compressibility at 75° is unusual.

The mean linear thermal expansion at atmospheric pressure was 0.000013.

The resistance measurements were made with a cylindrical rod 6 mm in diameter and 2 cm long. Current connections were made at the ends by flat electrodes contacting over the entire plane end, pulled together with steel springs, and with a film of "aquadag" cement under the electrodes to ensure good contact. The potential taps were silvered steel spring clips embracing the entire specimen. Measurements were made only at 30°. The effect of pressure on resistance is very large and negative, resistance at 12000 dropping to 1/725th of the initial value. The curve did not exactly retrace itself with decreasing pressure, but there was a permanent decrease of the zero resistance by 10% of itself. The results are given on a logarithmic scale in Table III and are shown graphically in Figure 2. There is a point of inflection in the curve of log R vs pressure, at pressures above the inflection point log R becoming convex toward the pressure axis. Convexity toward the pressure axis is also characteristic of all other substances yet measured with very large negative effects; it is suggestive of a minimum resistance at much higher pressures.

TABLE III

RESISTANCE OF Ag_2S UNDER PRESSURE at 30° C

Pressure kg/cm²	$\log_{10} R/R_0$
1	0.00
2000	−0.52
4000	−1.09
6000	−1.62
8000	−2.07
10000	−2.51
12000	−2.86

The resistance of Ag_2S under pressure has been previously measured by Montén[5] up to 3000 kg/cm.[2] Montén measured many samples, and found the results highly variable with the sample. As a rough average his results were about twice as great as found above.

PbSe. This material was synthesized from weighed amounts of the pure constituents by melting together in a quartz tube in a gas furnace. If the contents of the tube are allowed to solidify naturally after melting, a casting is obtained full of blow holes and entirely unsuitable for compressibility measurements. A homogeneous casting was obtained by solidifying the melt by slowly lowering the quartz tube through the bottom of the furnace, essentially like my method of making single crystals. The specimen was subjected to a seasoning application of pressure before compressibility measurements were made. At 30° the mean deviation from a smooth curve of a single reading was 0.24% of the maximum effect, and at 75° 1.1%. The results were:

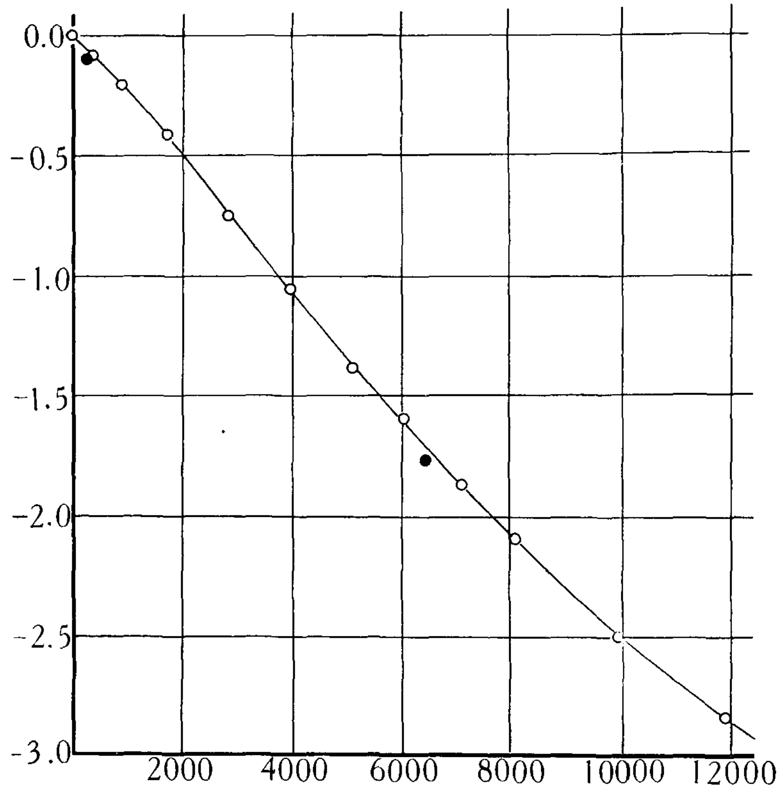

FIGURE 2. Logarithm to the base ten of the relative resistance at 30° of Ag_2S plotted as ordinates against pressure in kg/cm² as abscissa. The open circles were obtained with increasing pressure, the closed circles with decreasing pressure.

$$\text{At } 30°, \ -\Delta V/V_0 = 20.67 \times 10^{-7}p - 12.8 \times 10^{-12}p^2$$

$$\text{At } 75°, \ -\Delta V/V_0 = 21.00 \times 10^{-7}p - 14.1 \times 10^{-12}p^2.$$

The mean linear thermal expansion at atmospheric pressure was 0.000020.

No measurements were attempted of electrical resistance.

PbTe. The method of preparation and the preliminary treatment was like that of PbSe. The mean deviation from a smooth curve of a single reading was 0.28% of the maximum effect at 30°, and 0.25% at 75°. The results were:

$$\text{At } 30°, -\Delta V/V_0 = 25.55 \times 10^{-7}p - 24.3 \times 10^{-12}p^2$$

$$\text{At } 75,° -\Delta V/V_0 = 27.37 \times 10^{-7}p - 38.6 \times 10^{-12}p^2.$$

The mean linear thermal expansion at atmospheric pressure was 0.000022.

The compressibilities have now been measured for the three compounds PbS,[6] PbSe, and PbTe. There is, as would be expected, a regular progression, the initial compressibilities at 30°, for example, being respectively 18.4, 20.7, and 25.5 × 10^{-7}. All three compressibilities are markedly less than would be calculated by the simple rule of mixtures from the compressibility of the pure constituents, and the discrepancy between the actual compressibility and the compressibility calculated by the rule of mixtures is correlated with the contraction of volume on formation, which again is doubtless correlated with the internal pressure. Thus the actual compressibility of PbS is only one fourth of that calculated, and there is a volume contraction of 5% on formation, while the actual compressibility of PbTe is two thirds of that calculated, and there is a volume *expansion* of 5.9% on formation. The direction of correlation is thus what would be expected, a high volume contraction meaning a high internal pressure and a low compressibility.

$Ag_2SO_4.4NH_3$. This material crystallizes in the tetragonal system. I am indebted to Dr. R. W. G. Wyckoff for a large single crystal. This was large enough to permit cutting a compressibility sample in the direction of the tetragonal axis, but samples in other orientations could not be obtained. Successful readings were obtained only at 30°; at 75° part of the crystal was found to have crumbled and assumed a milky appearance after exposure to 1000 kg/cm². I did not try to determine whether this was due to a polymorphic transition or to chemical decomposition. At 30° the mean deviation of a single reading from a smooth curve was 0.41% of the maximum effect. The results were:

At 30°, parallel to the tetragonal axis:

$$-\Delta l/l_0 = 9.87 \times 10^{-7}p - 8.4 \times 10^{-12}p^2.$$

Basalt Glass. Measurements on this substance may be expected to be chiefly of geological interest; they were made at the suggestion of

Professor R. A. Daly. I have previously made measurements on two natural basalt glasses of different origins; one of these showed anomalous effects. The material now investigated was artificial basalt, which had been synthesized at the General Electric Co. in Lynn. It was in the form of a more or less homogeneous block, several inches in every dimension. Compressibility samples were sawed from this block in two directions at right angles. Measurements were made on each of these specimens at five temperatures, 0°, 30°, 50°, 75°, and 95°. Five temperatures were used instead of the usual two because it was especially desired to investigate the abnormal change with temperature of the direction of curvature previously found. It is not worth while to reproduce here the results in full detail; they have already been referred to by Birch and Law[7] in a paper dealing also with other results of geological interest.

The regularity of the results was not different from that of all this compressibility work. The results at different temperatures were consistent with each other, and in fact the variation with temperature was found to be linear. It is therefore sufficient to reproduce the results for two temperatures. The two samples gave essentially the same results, although those of one were somewhat more irregular than those of the other. It therefore seems justifiable to calculate the change of volume from the linear measurements by assuming the change of length uniform in every direction.

$$\text{At } 0^\circ, \ -\Delta V/V_0 = 15.62 \times 10^{-7}p - 7.6 \times 10^{-12}p^2$$

$$\text{At } 100^\circ, \ -\Delta V/V_0 = 15.84 \times 10^{-7}p - 1.7 \times 10^{-12}p^2.$$

At intermediate temperatures the proper expression may be found by assuming a linear variation with temperature of both coefficients.

At atmospheric pressure the mean linear thermal expansion is 0.000005.

The most interesting feature of the compressibility results is the very large drop with pressure of the coefficient of p^2. This will reverse sign at about 130°, so that above this temperature the compressibility will increase with increasing pressure. This reversal has been found to be characteristic of other varieties of glass at lower temperatures; it is particularly marked in those glasses which have a large SiO_2 content.

Corrected Compressibilities

In this section are collected the corrected values for my early compressibilities. As already explained in the introduction, there was an error in the sign of the correction term applied for reducing change of length to change of volume. This results in an error in the second degree term which is larger the larger the compressibility. This error does not occur in anything published later than 1925. There is however, a very slight correction to be applied to all my published compressibilities, because of the change in the fundamental compressibility of iron. The value used formerly in all the calculations was:

$$\text{At } 30°, \ -\Delta V/V_0 = 5.87 \times 10^{-7}p - 2.10 \times 10^{-12}p^2$$

$$\text{At } 75°, \ -\Delta V/V_0 = 5.93 \times 10^{-7}p - 2.10 \times 10^{-12}p^2.$$

The new values, corrected properly, making certain readjustments so as to secure a better fit on the original data, and giving an extra significant figure, which is sometimes useful in getting smoother results, are:

$$\text{At } 30°, \ -\Delta V/V(0, 30°) = 5.868 \times 10^{-7}p - 2.37 \times 10^{-12}p^2$$

$$\text{At } 75°, \ -\Delta V/V(0, 30°) = 5.925 \times 10^{-7}p - 2.31 \times 10^{-12}p^2.$$

The new values for the change of length, consistent with these values for the change of volume are:

$$\text{At } 30°, \ -\Delta l/l(0, 30°) = 1.956 \times 10^{-7}p - 0.75 \times 10^{-12}p^2$$

$$\text{At } 75°, \ -\Delta l/l(0, 30°) = 1.975 \times 10^{-7}p - 0.73 \times 10^{-12}p^2.$$

All the compressibilities published since 1925 should strictly be corrected by a constant additive term, the difference between the former and the corrected values of the compressibility. The difference is of very minor importance in all cases.

The corrected early compressibilities are now given in Table IV. Lithium, sodium and potassium are not given here, because the corrected values have already been given in another paper.[8] Also all values for non-cubic metals are omitted, because these have been replaced since 1925 by values for the single crystals. There are also several cubic metals for which improved values had been given in papers since 1925, and these are also omitted. In some cases the original data were given for several samples of a metal of different grades of purity; only the results for the purest are reproduced here. All in all, the number of data which require correction is not very large.

TABLE IV

Corrected Compressibilities

$$-\Delta V/V\ (0, 30^\circ) = a \times 10^{-7}p - b \times 10^{-12}p^2$$

Substance	30°		75°	
	a	b	a	b
Al	13.43	6.2	13.75	6.2
Ca	56.97	63.9	58.49	76.1
Co	5.39	−2.3	54.7	−2.3
Cu	7.19	3.0	7.34	−3.0
Ge*	13.77	−7.9	13.63	−7.8
Au	5.77	−3.4	5.70	−2.3
Pb	23.72	20.3	24.33	21.0
Mo	3.60	1.19	3.61	1.10
"Nichrome"	5.50	1.8		
Ni	5.29	2.4	5.35	2.3
Pd	5.28	2.4	5.31	2.3
Pt	3.60	1.8	3.64	1.8
Ag	9.87	5.06	10.04	4.5
Sr	81.22	100.6	82.11	101.4
Ta	4.79	.4	4.92	.5
Ur	9.66	3.26	9.55	2.78

* See improved value on p. 305 of this paper.

Discussion

This discussion will be concerned only with the intermetallic compounds; the other substances have already been sufficiently discussed incidentally in the text.

The most striking characteristic of the results for intermetallics as contrasted with other substances is their much greater irregularity. The most common sort of irregularity is pressure hysteresis, both in compressibility and resistance. This hysteresis may in some cases assume very marked proportions, as in the very striking resistance hysteresis of Ag_2Al at 75°. In addition to hysteresis, there are often creep phenomena, shown more often by the resistance than by the volume, and also breaks of one kind or another, breaks in direction or actual small discontinuities. These breaks are more often shown by the compressibility than by the resistance, but the resistance does sometimes show distinct breaks, as Ag_5Cd_8, for example. In this connection it must be remembered that the compressibility measurements are in general more sensitive than those of resistance. Finally, there are long range time effects, the pressure at which a break occurs being displaced when the specimen rests for months or a year or more.

All of these irregularities point to a condition of internal equilibrium shifting under the action of pressure and in some cases with the passage of time. This is what might be expected in view of the present picture of the nature of an intermetallic compound. These are not to be thought of as compounds in the sharp definite sense of the conventional chemical compound. In at least some cases they are rather statistical compounds, there being a maximum in the number of ways in which a certain sort of superstructure can be built up as the ratio of the atomic species passes through certain critical values. The most recent X-ray analysis shows that these superstructures are in many cases more complicated than was at first supposed. Thus, it now appears that Sn_8Cu_{31}, with its electron-atom ratio of 21 to 13 or 1.616, is only an approximation, the unit cell now being supposed to contain 416 atoms, giving $8Sn_{11}\,Cu_{41}$ as a possible formula, with an electron-atom ratio of 1.634. With such large superstructures playing an actual part it seems that there must be a wealth of possibilities for the production of new structures by pressure, and it may be that the breaks found above are due to this sort of thing. Furthermore, it would seem natural to expect that the forces tending to build up such large structures must be comparatively weak, so that the control exerted by them would be more or less indefinite, suggesting the possibility of marked hysteresis.

In spite of the irregularities, there are certain general trends evident in the results. In Table V are collected a number of comparative data, including the observed and "calculated" initial compressibilities at 30°, the observed and "calculated" specific resistances at 30°, and the volume contraction, which is essentially a comparison of observed and "calculated" volume. The "calculated" values were obtained on a volume basis. For example, the "calculated" compressibility of Ag_5Cd_8 was obtained by the formula:

$$\frac{5 \times (At.\ vol.)_{Ag} \times \kappa_{Ag} + 8 \times (At.\ vol.)_{cd} \times \kappa_{cd}}{5 \times (At.\ vol.)_{Ag} + 8 \times (At.\ vol.)_{cd}},$$

where κ_{ag} means the initial compressibility of Ag at 30° etc. The resistance and volume were calculated by substituting in this formula specific resistance and specific volume instead of κ. In calculating the volume I am very much indebted indeed to Professor L. W. McKeehan for access to an unpublished compilation which he has made of all the latest X-ray parameters of the intermetallic compounds. The X-ray data do not always exactly correspond to the

COMPARISON OF VARIOUS EXPERIMENTAL PROPERTIES OF THE INTERMETALLIC COMPOUNDS WITH THE "CALCULATED" VALUES

Compound	Compressibility × 10^7			Specific Resistance × 10^6			Volume Contraction Per Cent
	Calculated	Observed	$\frac{\text{Obs.}}{\text{Calc.}}$	Calculated	Observed	$\frac{\text{Obs.}}{\text{Calc.}}$	
Ag_5Cd_8	18.5	12.4	.67	5.79	13.1	2.26	4.6
Ag_5Sn_8	13.8	11.5	.83	4.45	21.5	4.83	2.1
Cu_5Cd_8	18.7	16.3	.87	6.30	17.3	2.74	5.2
Cu_5Sn_8	13.5	8.5	.63	4.91	10.7	2.17	4.3
$Cu_{31}Sn_8$	12.1	8.8	.73	7.15	49.4	6.91	−2.2
CuSn	15.8	8.9	.57	11.2	4.7	.42	5.0
AgCd	17.0	11.5	.68	5.12	6.6	1.29	5.3
AuSn	10.9	7.5	.69	4.34	7.95	1.83	3.2
AgSn	13.1	10.3	.78	3.91	6.0	1.53	2.8
Cu_5Sn	11.4	8.2	.72	6.40	27.5	4.29	
Ag_2Al	11.0	10.1	.92	2.06	29.7	14.4	
Mg_3Al_2	24.4	24.7	1.01	4.19	92.3	22.1	−3.7
Mg_2Pb	27.3	26.1	.96				
$MgSn_2$	22.2	16.6	.75	5.72	25.6	4.47	
SbSn	22.6	22.2	.98	27.9	28.4	1.02	0.0
$AuSb_2$	22.4	11.4	.51	34.0	29.0	.85	6.0
Sb_2Tl^7	27.6	32.1	1.16	24.9	88.5	3.55	.7

theoretical compositions, but the differences probably are in most cases not of much significance. The most important divergences between the most recent formulas and those used above are, in addition to Sn_8Cu_{31}, already mentioned, Mg_3Al_2, which is now given preferentially as $Mg_{17}Al_{12}$, and $SnCu_5$, which is now said to contain only two atoms in the unit cell, and to have the proportions $2(Sn_{0.15}Cu_{0.85})$, the notation indicating only a statistical regularity.

Perhaps the most striking feature brought to light by the Table is that the calculated compressibility is almost always markedly greater than the actual compressibility. This is what would be expected if there were important chemical affinity in the intermetallic compounds, a high chemical affinity meaning a high internal pressure, which in turn means a lowered compressibility. There do not seem to be data for the thermal effects on formation which would permit a quantitative correlation, but it is common experience that the thermal effects on alloying metals may often be large. Similar considerations would lead one to expect the volume contraction on formation to be important. It does turn out in most cases that there is a contraction, but there are two cases of volume expansion, and there is no close correlation between volume contraction and compressibility. For instance, Sn_8Cu_{31} has a volume expansion of 2.2%, but a considerable decrease of compressibility, the ratio being 0.73. On the other hand, Mg_3Al_2 has the largest volume expansion, 3.7%, and shows no diminution of compressibility.

The specific resistance is almost always larger than would be calculated from the rule of mixtures. This is what would be expected on general grounds because of the breaking up of the structure when different sorts of atom are present, and the consequent interference with the passage of electron waves. In general, the discrepancy between calculated and observed resistance is much larger than for the compressibility, which again is what might be expected, because resistance is much more sensitive to slight imperfections in the structure. It must be kept in mind, however, that the formula by which the resistance is "calculated" has no rigorous foundation, the resistance thus calculated corresponding to what would be found if the different sorts of atom were lined up in series, which certainly does not occur. There are two important exceptions to the general rule with regard to specific resistance; CuZn has a very low specific resistance and an observed-calculated ratio of only 0.42, and $AuSb_2$ has a ratio of 0.85.

A correlation would be expected between temperature coefficient of resistance and specific resistance, a high temperature coefficient and also a low specific resistance being associated with the pure metals. If one plots temperature coefficient against ratio of observed to calculated resistance a sort of correlation will be found, the high coefficients and low ratios having a tendency to go together, but the correlation is very rough.

The temperature coefficient of AgZn, 0.00489, is noteworthy because it is so high, materially higher than that of either constituent metal.

The pressure coefficients of resistance are almost always negative, as are also most of the pure metals, but the coefficients of the compounds are in general distinctly less numerically than those of the metals. This again is what might be expected on the basis of previous experience, positive coefficients not being rare among the alloys. There does not seem, however, to be any obvious more detailed correlation.

I am indebted to Mr. L. H. Abbot for making the readings. I am

also indebted to the Rumford Fund of the American Academy for financial assistance in the purchase of supplies, and to the Francis Barrett Daniels Fund of Harvard University for general financial assistance.

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Proceedings of the American Academy of Arts and Sciences

Vol. 70, No. 8—February, 1936

THE SPECIFIC VOLUME OF STEAM IN THE SATURATED AND SUPERHEATED CONDITION TOGETHER WITH DERIVED VALUES OF THE ENTHALPY, ENTROPY, HEAT CAPACITY AND JOULE THOMSON COEFFICIENTS

Part IV. Steam Research Program

By

Frederick G. Keyes, Leighton B. Smith, and Harold T. Gerry

(Continued from page 3 of cover.)

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By

Frederick G. Keyes, Leighton B. Smith, and Harold T. Gerry

(Contribution from the Research Laboratory of Physical Chemistry,
Massachusetts Institute of Technology, No. 360)

THE SPECIFIC VOLUME OF STEAM IN THE SATURATED AND SUPERHEATED CONDITION TOGETHER WITH DERIVED VALUES OF THE ENTHALPY, ENTROPY, HEAT CAPACITY AND JOULE THOMSON COEFFICIENTS

PART IV. STEAM RESEARCH PROGRAM[1]

BY

FREDERICK G. KEYES, LEIGHTON B. SMITH, AND HAROLD T. GERRY

Received 3 December, 1935 Presented 11 December, 1935.

THE most comprehensive data on water vapor or steam volumes were published by Knoblauch, Linde and Klebe[2] thirty years ago. Since this publication, increased pressures and temperatures have been applied in the generation and use of steam for power until at the present time 80 atm. turbines and boilers are not uncommon and superheated steam to temperatures approaching 650° C are being considered. The insufficient range of the earlier measurements in pressure (11 atm.) and in temperature (190° C) for present day steam applications is evident, and for this reason the Steam Research Committee[3] of the American Society of Mechanical Engineers in 1921 requested the precise measurement of steam volumes to temperatures and pressures as high as modern experimental technique would permit.

The designers of boilers and steam power machines have not only used the new data as rapidly as it could be obtained from the reports presented at the annual meetings[4] of the American Society of Mechanical Engineers, but have in the past fifteen years pushed forward tentative machine designs for use at higher pressures and higher temperatures faster than exact data could be provided for definitive machine design.

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[1] The earlier papers of this series appeared as follows: Part I, Proc. Am. Acad. of Arts and Sciences, *68*, 505 (1933); Part II, ibid., *69*, 137 (1934); Part III, ibid., *69*, 285 (1934)

[2] Knoblauch, Linde and Klebe, Mittheilung über Forschungsarbeiten, Heft 21, 1905.

[3] Mech. Eng. *43*, 557 (1921).

[4] A list of these reports is given in Part I, p. 506, of the present series of papers.

At the moment the superheat temperatures of steam in actual use exceeds the upper limit of temperature (460° C) reached in the volume measurements to be reported. The range of pressure and temperature, however, over which exact measurements have been made is now so great that extrapolation to higher temperatures may be undertaken with considerable confidence. This opinion is amply supported by the comparisons of derived quantities obtained from the extrapolated volume data with similar measured quantities* obtained by colleagues in England, in Germany and in Czechoslovakia.

The economic importance of reliable steam data for engineering purposes is evident. The purely scientific importance of exact data on the properties of water is no less evident, for without extensive data no finally satisfactory correlations of important properties of aqueous solutions and other physico-chemical phenomena can be made. The data should therefore prove especially valuable in interpreting solubility effects at higher temperatures, a region of great practical significance on account of the role water plays in many geological phenomena.

The new data is of use also in connection with the development of the theory of molecular forces; a knowledge of which is of the most fundamental importance in correlating such diverse properties of matter as the departure from the ideal gas laws, viscosity, surface tension, adsorption properties, phase transformation, density dependance of dielectric constants and chemical interaction under pressure. Water consists of molecules possessing a permanent dipole and in consequence the molecular field is more complicated in its dependance on the distance of separation of the molecules than, for example, the atoms of the rare gases, hydrogen, oxygen, carbon dioxide,—gases which do not possess permanent dipoles. At the present time, p, v, T data for dipole gases is not abundant and besides ammonia there is very little data over an extended range of temperature.

The present measurements of steam volumes at various pressures and temperatures have been obtained by the methods and procedures described in Part I of the Steam Program Series of papers. The data have been presented, as obtained during the past decade, at the annual December meetings of the Steam Research Committee but neither in detail nor accompanied by an adequate discussion of their probable precision. Often also, the data for introducing certain corrections had not been obtained at the time of the annual reports and moreover important improvements were introduced in subsequent measurements which modified the numbers given in the running series of progress reports. In the present paper all the data taken have been reduced from the original measurements introducing every refinement possible in correcting the results for container dilation with temperature and pressure, for gauge "constant" drift with time, for volumnometer irregularities, for gauge weight calibrations, for the effects of thermometry errors, and for other effects connected with the peculiarities of the measuring procedures.

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* Privately communicated.

Many samples of water were used in several types of container constructed of different materials. The larger specific volumes were confined with mercury which limited the temperature to which the measurements could be carried due to the present lack of knowledge of the properties of mercury and mercury-water gas phase mixtures. On the other hand, measurements at lower temperatures and necessarily low pressures, are affected by adsorption to such an extent that below 190° C the attempt to continue the use of the static method of measurement was abandoned in favor of a new method.

Of course the older measurements of Knoblauch, Linde and Klebe are in the range below 190° C and were obtained by using a static method, thus making confirmation by an independent method especially desirable. Two modifications of the static method have been used above 190° C in the work upon which the present paper is based; and the development of a new method was undertaken in the autumn of 1929, whereby the departure of steam from the ideal gas laws could be measured directly with the fluid in a state of steady motion.[5] Adsorption under conditions of steady motion of the steam has no disturbing influence whatever on the measurements of interest. The method was first tested by using ammonia and carbon dioxide, fluids for which accurate low pressure p-v-T data are available for comparison purposes.

The new method[6,7] was applied to steam in 1933 and 1934, and supplied sufficient data to permit the correlation of steam volumes over the lower range of temperature. Since June 1934 the entire apparatus has been redesigned to give results of greater precision and useful for a greater range of temperature and pressure. In a later paper a detailed account of the apparatus will be given together with a comprehensive series of measurements of $\left(\frac{\partial H}{\partial p}\right)_T$ and the Joule-Thomson effect for steam, both of which may be obtained simultaneously in the same apparatus if desired.

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[5] See Part I, footnote 38, p. 543.

[6] F. G. Keyes and S. C. Collins, Proc. Nat. Acad. Sci. *18*, 328 (1932).

[7] F. G. Keyes and L. B. Smith, Mech. Eng. *55*, 114 (1933).

The temperature scale employed in the measurements has already been referred to in Part I, Section 5, and is that of the platinum electrical resistance thermometer interpreted by means of the Callendar difference formula. The relation of the thermodynamic scale of temperature to the International scale[8] is of evident importance and since the writing of paper, Part I, several scores of observations of the relation of the nitrogen gas scale to the international platinum scale have been carried out in this laboratory by our colleague, Professor James A. Beattie and his collaborators. In addition, exhaustive investigations of the important fixed point, the boiling point of sulphur, have reached a stage where publication may soon be expected. The precision of the steam data secured at M.I.T. and by our colleagues is sufficiently great to make the difference between the International Kelvin scale and the thermodynamic scale deduced from the gas scale readings of great interest. The nature of the results of the M. I. T. thermometric studies emphasizes moreover the importance of independent investigations which will give precision to the calculation and comparison of derived and measured thermodynamic quantities. Certainly it now seems improbable that a final decision regarding the thermodynamic consistancy of the existing mass of steam data will be reached until the relation of the present international scale and the thermodynamic scale is known to within possibly 0.01° C over the temperature range of the measurements. The latter quantity appears to be about the order of magnitude of the reproducibility attained in the practice of thermometry by the workers in the different laboratories cooperating in the steam investigation.

THE VOLUME DATA FOR STEAM

In Table II of paper Part I the several types of container used were listed along with their internal volumes and the coefficients of thermal expansion. The smaller specific volumes were measured by confining the water sample with the liquid phase, Fig. 9 Part I. In using this method the chief inaccuracy arises in the location of the meniscus between the vapor phase and liquid phase in the container capillary just above the surface of the molten salt bath. This uncertainty is small, the less the steam pressure relative to the saturation pressure.

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[8] Burgess, U. S. Bur. of Stand. Jour. of Research, *23*, 635 (1928).

Near saturation it was necessary to wait for long periods before an equilibrium was attained, but the final perfection of the capillary cooler-heater (Fig. 10 Part I) made it possible to locate accurately the two phase miniscus, thereby expediting the measurements and increasing the precision of measurement. The device made it possible to make measurements within a small fraction of an atmosphere of the saturation pressure and in this way virtually observe directly the volume of the saturation state.

The measurements by the static method were made by observing the pressures and temperatures corresponding to a selected constant volume. The constant volume lines for any fluid are nearly linear on the *t*, *p* plane, and in determining the true saturation volume the isometrics were extrapolated both graphically and analytically, to find the temperatures corresponding to the saturation pressures. A test of the correctness of the saturation volumes may be obtained through the Clapeyron relation comparing the computed heats of evaporation with similar quantities measured by our colleagues at the U. S. Bureau of Standards. The only uncertainty in these comparisons arises from our imperfect knowledge of the relation of the indications of the platinum resistance thermometer to the thermodynamic scale.

The data obtained in the nickel container, No. 1,[9] are not reported in the present paper. These data while consistant to nearly one part in three thousand for two separate samples of water did not prove to be consistant with similar measurements made in stainless steel. No entirely satisfactory explanation of the discrepancy has been found but evidence was obtained indicating that a slow decomposition takes place with water in contact with nickel whereby nickel oxide is formed and the hydrogen completely absorbed by the metal. Our knowledge of the rate of this phenomenon is not definite and it does not appear finally satisfactory to assign all the discrepancy to the interaction. Whatever the complete account of the difficulty may be, the older measurements are certainly not in accord with repeated measurements in stainless steel in two forms of container using the water-confining and mercury-confining method.

Most of the data given in Table I have been reported in the December A. S. M. E. meetings but the numbers will be found to differ somewhat therefrom. These differences arise from a recomputation of all the directly observed data and the application of various corrections which could not be applied for lack of data at the time of the interim reports. One of the most important of the corrections is the drift of the pressure gauge "constants" with time; an effect long suspected but not definitely settled until rather late in the steam program.* Duplicate measurements were made using different containers and varying total loadings of water, and this together with variations in general conditions provides a test of reproducibility. The absolute accuracy of the data may be judged by employing the data to derive thermodynamic quantities which may be compared with directly measured quantities. We refer particularly to comparisons of latent heats computed by means of the Clapeyron relation, values of the enthalpy, the specific heats and Joule-Thomson effect values.

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[9] L. B. Smith and F. G. Keyes, Mech. Eng. *53*, 125 (1931).

The Analytical Formulation of the Data

A formulation of the data was recently published[10] and in the spring and summer of 1934 a reformulation was carried out[11] resulting in a somewhat better representation of the data. In the second formulation fewer constants (9 in place of 12) were used and a simpler equation in the form $v = f(p, T)$ was developed valid to 10 cc. per gram on the vapor saturation line. It would be desirable to have available an analytical representation to the smallest volumes but thus far it has not been found possible to develop a single equation satisfactory for the entire range from infinite volumes to, say 2 cc. per gram. It is possible without great difficulty to represent a greater range of the data when the pressure is represented as an explicit function of the volume and temperature.

The equation of state of a real gas at low pressures may be very satisfactorily derived on a rational basis when the value of the intramolecular potential is known.[12] In the case of a substance such as water composed of molecules possessing a permanent dipole, the molecular field is much more complicated[13] as compared with non-polar molecules of which the rare gases hydrogen, nitrogen and carbon dioxide are examples. However there is enough evidence indicating that the potential corresponding to the attractive forces is very large compared to the potential of the repulsive forces in the case of the water molecule. This makes it possible to employ as a sufficient approximation the van der Waals molecular model where the potential of the repulsive forces is assumed to be infinite on molecular contact. Actually, of course, our knowledge of molecular structure has progressed sufficiently to make clear that the older concept of definite and sharp molecular boundaries has lost meaning. The approximation attending the assumption of infinite repulsive potential is however, for equation of state purposes increasingly better as the attractive potential becomes larger. The facts can be illustrated by reference to Figure 1, where the true course of the potential, V, as a function of the distance, r, is represented by the full line, while the dotted line represents conditions on the assumption that at distance σ an infinite positive or repulsive potential is encountered. It is clear that the larger the area inclosed between the negative potential curve and the r axis, the better the approximation will be for van der Waals' assumption regarding molecular forces, since the ratio of the shaded area to the whole area becomes small. Helium, hydrogen, neon offer examples of substances where the attractive potential is very small relative to the repulsive potential and the error introduced by van der Waals' assumption is far too great to be ignored. In these cases a more general form of potential must be used as for example that which sufficed very well in the case of helium where $V = c\,e^{-ar} - br^{-6}$.[14] The simple expression $V = C_1 r^{-14} - br^{-6}$ is also reasonably successful in representing the behavior of helium and hydrogen.

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* About 1930.

[10] F. G. Keyes, L. B. Smith and H. T. Gerry, Mech. Eng. *56*, 87 (1934).

[11] F. G. Keyes, L. B. Smith and H. T. Gerry, Mech. Eng. *57*, 164 (1935).

[12] R. H. Fowler, "Statistical Mechanics," 1929, Chap. 8. F. G. Keyes, Chem. Rev., *6*, 175 (1929). J. G. Kirkwood and F. G. Keyes, Phys. Rev., *37*, 832 (1931).

[13] J. G. Kirkwood, J. Chem. Phys. *1*, 597 (1933).

To derive the equation of state it is convenient to use the phase integral of Gibbs.[16] For the case of a gas at not too great pressures it can be shown[17] that the equation of state may be written as follows:

$$p = \frac{RT}{v - B^\circ} \qquad (1)$$

where B_o is given by the equation

$$-B^\circ = 2\,\pi\,N \int_0^\infty \left(e^{-\frac{Pot}{kT}} - 1\right) r^2\,dr \qquad (2)$$

N is Avogadro's number, "*Pot*" represents the molecular potential and k is Boltzmann's constant. If the van der Waals assumption is

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[14] Slater and Kirkwood, Phys. Rev., *37*, 682 (1931). Kirkwood and Keyes, Phys. Rev., *37*, 832 (1931).

[16] Gibbs, "Elementary Principles of Statistical Mechanics" Equation 92.

[17] F. G. Keyes, Chem, Rev. *6*, 202 (1929).

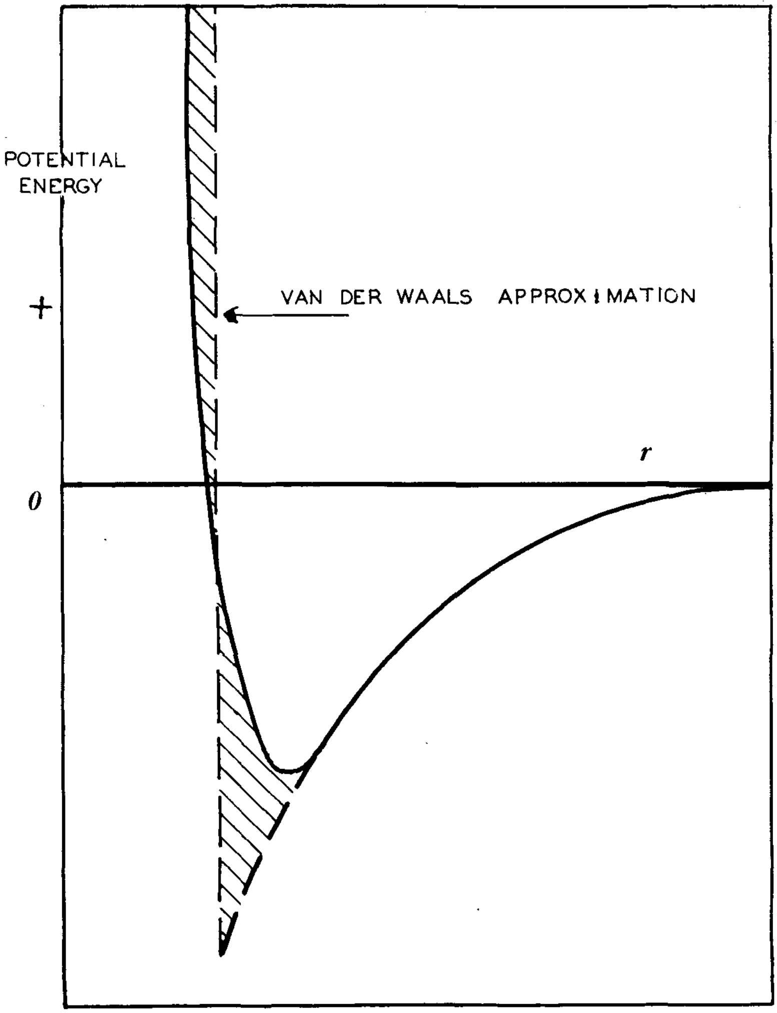

FIGURE 1

made and the attractive potential is assumed to vary as the inverse sixth power of distance[18] equation (2) may be solved and we obtain:

$$B_o = \beta - \frac{A}{RT} \sum_{j=1}^{j=\infty} \frac{1}{(2j-1)\,j!} \left(\frac{A}{RT\beta} \right)^{j-1} \tag{3}$$

where β and A are constants.

Water vapor, or steam, is composed of molecules possessing a permanent dipole and the attractive potential cannot be represented as a satisfactory approximation by a simple inverse sixth power term. The correct general expression has been recently given by Kirkwood[19] who showed that the average attractive potential consists of three terms, or rather three groups of terms. One term containing the temperature arises from the rotating dipole. There is a second term of inverse sixth power similar to that for non-polar molecules and finally a composite third term. This general potential expression by Kirkwood may be used to compute B° for water but the slow convergence of the series of terms similar to the summation in equation (3) made the use of the equation at low temperatures very inconvenient. It was found however that an empirical sum-expression could be devised which represented satisfactorily the values of B_o obtained from the measurements. The final expression obtained for B° in the case of steam is the following:

$$\frac{c.c.}{g.} B_o = 1.89 - 2641.62\,\tau\,10^{80870\tau^2} \tag{4}$$

where τ is used to represent T^{-1}. In obtaining this equation the volume data of Table I was employed but the lowest temperature available was somewhat below 200. It is true that we have available the 1905 measurements of Knoblauch, Linde and Klebe, but these were determined by the static method which in our hands did not seem a reliable method below 190° because of adsorption of the water vapor on the walls of the container. Instead of using the K. L. and K. data, use was made of values of $\left(\frac{\Delta H}{\Delta p}\right)_T$, where H represents the enthalpy, measured directly using the "flow" method already mentioned. The values of $\left(\frac{\Delta H}{\Delta p}\right)_T$ were measured at low pressures ($\Delta p = p_2 - p_1$), and can be accurately represented as linear functions of pressure as follows: $\left(\frac{\Delta H}{\Delta p}\right)_T = \psi_o + \frac{1}{2}\varphi_1 (p_2 + p_1)$. From the latter type of formulation values of $\psi_o = \frac{\partial B_o \tau}{\partial \tau}$ may be derived and used to extend the B_o curve. The lowest temperature for which direct experimental data are available is 60°.

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[18] The assumption that a simple inverse sixth power term represents the potential is of course not strictly correct. There are higher order terms, a quadrapole and even higher orders with combination terms which play an increasing rôle as the distance between molecular centers diminishes. The use of the inverse sixth power may in consequence be regarded as an approximation.

[19] J. G. Kirkwood, J. Chem. Phys. *1*, 597 (1933).

The theory of the equation of state is not at a stage where a suitable expression for high pressures may be derived. Moreover the "natural" form of the equation of state comes from the theory giving p as a function of v and T, or what amounts to the same thing, B as a function of v and T, whereas convenience in computing many thermodynamic quantities requires that v be given explicitly in terms of p and T. The most suitable procedure at present appears therefore to attempt to represent B in equation (1) as $B = B_o + \varphi_1 p + \ldots\ldots \varphi_n p^n$ where $\varphi_1 \ldots\ldots \varphi_n$ are temperature functions. After considerable experience accumulated in the course of numerous attempts to represent the steam data accurately, the following form for B was adopted:

$$B = B_o + \varphi_1 p + \varphi_3 p^3 + \varphi_{12} p^{12} \tag{5}$$

The first step in the process of securing the constants used to represent the temperature functions B_o, φ_1, φ_3 and φ_{12} is to obtain "B" values $\left(B = v - \frac{RT}{p}\right)$ corresponding to the pressures and volumes along isotherms. In this way a series of equations at all temperatures can be prepared by least squares as follows:

$$\begin{gathered} B_{t_1} = B_{o_{t_1}} + \varphi_{1_{t_2}} p + \varphi_{3_{t_1}} p^3 + \varphi_{12_{t_1}} p^{12} \\ B_{t_2} = B_{o_{t_2}} + \varphi_{1_{t_2}} p + - - - - - \\ - \\ B_{t_n} = B_{o_{t_n}} + \varphi_{1_{t_n}} p + \varphi_{3_{t_n}} p^3 + \varphi_{12_{t_n}} p^{12} \end{gathered} \tag{6}$$

To correlate the B_{o_t} terms by least square procedure, a form of temperature function was chosen in accordance with the theory already discussed. The explicit expression has already been given as equation

Container→ Vol. $\frac{\text{cc.}}{\text{g.}}$ → t ↓	1B 2.0	1B 3.0	1B 4.0	1B 5.0	1B 6.25	1B 7.5	1B 10.0	1B 12.5	1B 15.0	1B 17.5	2B 2B′ch. 20.0	2B 2B′ 20.0	1B 20.0	2B 2B′ch. 30.0	2B 2B′ 30.0	2B 2B′ 39.5	2B 2B′ 40.0	2 2′ 40.0	2B 2B′ch. 40.0	2B 2B′ 40.0	2B 2B′ch. 50.0	2B 2B′ 50.0	2 2′ 57.5	2B 2B′ 75.0	2 2′ 75.0	2 2′ 97.5	2B 2B′ 100.0	2B 2B′ 140.0	2′ 150.0	t
195.0																												13.787		195
196.0																												13.898		196
197.0																												13.957		197
198.0																												14.003		198
199.0																												14.040		199
200.0																												14.074	13.220	200
210.0																												14.479	13.591	210
212.5																											19.612			212.5
220.0																										20.514	20.086	14.871	13.952	220
227.5																								26.238						227.5
230.0																								26.482	26.503	21.106	20.664	15.252	14.302	230
240.0																								27.303	27.309	21.688	21.217	15.627	14.647	240
250.0																					39.388	39.052	34.983	28.082	28.099	22.258	21.769	16.014	14.986	250
251.0																														251
260.0																					40.592	40.469	36.051	28.854	28.869	22.816	22.297	16.366	15.323	260
264.0																49.164			48.827	48.689										264
265.0																			48.996											265
270.0																50.322		49.856	49.855	49.753			37.090	29.592	29.618	23.365	22.825	16.745	15.658	270
280.0																52.008		51.533	51.511	51.417	43.088	42.988	38.104	30.345	30.355	23.905	23.356	17.087	15.990	280
281.0														63.730	63.622															281
290.0														65.921	65.821	53.635		53.123					39.101	31.055	31.081	24.437	23.863	17.448	16.319	290
300.0														68.220	68.145	55.229		54.665	54.708	54.613	45.483	45.366	40.078	31.767	31.794	24.964	24.378	17.802	16.646	300
305.0											90.604	90.499																		305
305.5													90.765																	305.5
306.0											91.143																			306
310.0													92.582			56.745	56.192	56.169					41.035	32.476	32.496	25.485	24.881	18.146	16.971	310
313.0										101.287																				313
320.0										104.286	96.301	96.449	96.342	72.611	72.568	58.261	57.638	57.642	57.711	57.643	47.751	47.688	41.980	33.154	33.188	26.001	25.391	18.502	17.297	320
322.0									113.965																					322
330.0									118.413	108.690			100.009			59.718	59.102	59.096					42.915	33.857	33.870	26.514	25.892	18.839	17.620	330
332.5								130.593																						332.5
340.0								135.657	123.725	112.988	103.654	103.627	103.589	76.841	76.832				60.646	60.586	49.985	49.914								340
344.5							151.833																							344.5
350.0							156.607	142.215	128.838	117.154			107.103																	350
357.5						178.402																								357.5
360.0						181.389	165.137	148.566	133.857	121.235	110.504	110.456	110.525	80.900	80.841				63.497	63.428	52.188	52.105								360
364.5					194.118																									364.5
370.0	220.025				201.951	193.226	173.384	154.741																						370
371.5				210.784																										371.5
375.0		220.644	219.842																											375
380.0	267.878	234.370	230.931	225.819	216.133	204.683	181.385	160.516	143.453	129.679	117.092	117.049	117.105	84.845	84.804				66.279	66.225	54.308	54.257								380
390.0	317.298	262.404	252.748																											390
400.0	367.654	290.947	274.367	260.715	243.518	226.821	196.909	172.435	152.670	136.666	123.436	123.400	123.535	88.678	88.674				69.015	68.963	56.426	56.384								400
410.0		319.801	295.536																											410
																														420

(4). Using the smoothed set of B_o values a new set of φ terms were derived using transformed equations of the form $(B - B_o)/p = \varphi_1 - \varphi_3\, p^2 + \varphi_{12}\, p^{11}$. The φ_1 terms resulting were next correlated by least square procedure after a suitable empirical form for φ_1 had been developed. The form adopted was as follows:

$$\varphi_1 = B_o^2\, g_1\,(\tau)\,\tau \tag{7}$$

With the smoothing function for φ_1, a set of new functions was again computed, namely $[(B - B_o)/p - \varphi_1]\; 1/p^2 = \varphi_3 + \varphi_{12}\, p^9$. Another set of φ_3's and φ_{12}'s was then obtained and as in the case of φ_1 a smoothing function φ_3 was developed. The form for φ_3 was the following:

$$\varphi_3 = B_o^4\, g_2\,(\tau)\,\tau^3 \tag{8}$$

Finally, using the values of φ_3 from this smoothing function, the function $\left[\left[\dfrac{B - B_o}{p} - \varphi_1\right]\dfrac{1}{p^2} - \varphi_3\right]\dfrac{1}{p^9} = \varphi_{12}$ was computed. The φ_{12} values so obtained were then smoothed by determining the constants of the following form by least square computation.

$$\varphi_{12} = B_o^{13}\, g_3\,(\tau)\,\tau^{12}$$

The equation of state with the numerical values of the constants determined by least square procedure is given in full below.

$$p = \frac{4.55504\; T}{v - B}\,;$$

$$T = (273.16 + t°C)$$

mol wt. H_2O — 18.0154
pressure in international atm.
volume in cc. per gram of steam.

$$\begin{aligned}
B &= B_o + B_o^2\, g_1\,(\tau)\,\tau p + B_o^4\, g_2\,(\tau)\,\tau^3 p^3 - B_o^{13}\, g_3\,(\tau)\,\tau^{12}\, p^{12}\\
B_o &= 1.89 - 2641.62\,\tau\; 10^{80870\tau^2}\\
g_1(\tau) &= 82.546\,\tau - 1.6246\; 10^5\tau^2\\
g_2(\tau) &= 0.21828 - 1.2697\; 10^5\tau^2\\
g_3(\tau) &= 3.635\; 10^{-4} - 6.768\; 10^{64}\tau^{24}
\end{aligned} \tag{9}$$

The equation is valid to 10 cc. per gram at saturation pressure and temperature but not reliable along the saturation line to smaller volumes. At higher temperatures, however, the pressures corresponding to somewhat smaller volumes may be reliable. At this point it is apropos to note that the coefficients of the pressures become rapidly of lesser significance when higher temperatures are in question. As an example, the p^{12} coefficient at 400° C is more than 24000 times smaller than the same coefficient at 300°. The coefficient of p^3 at 400° is however somewhat less than 16 times smaller than the same coefficient at 300° while the ratio in the case of the coefficient of p is 3.56. The order of importance of the coefficients is therefore evident and it is equally evident that a very rapid simplification of the equation of state takes place as higher temperatures are approached. It is for this reason that the use of the equation for extrapolation purposes to give the volume of steam at high temperatures appears reliable provided volumes less than 10 cc. per gram are not in question.

The representation of B as a function of temperature and density is much easier than as a function of temperature and pressure. Nevertheless to represent the data to volumes as small as 3 cc. per gram has proved difficult. The selection of the simplest function consistent with precision in representing the data has not yet been made. For this reason no temperature-volume function will be given in the present paper but an equation will be given in a succeeding paper.

The Representation of the Data

Instead of tabulating the computed pressures or computed volumes using the equation of state 9 for comparison with the measured values, the following tables have been prepared giving a comprehensive survey of the degree of accord secured.

TABLE II

Deviation in Percent of Volumes Observed Less Calculated Using Equation 9. Steam Confined with Mercury

Container No.	Vol. cc./g. t	200	210	220	230	240
2	150	0.096	0.034	0.004	0.018	0.034
2B	140	.079	.001	−.031	−.027	−.009
2B	100			.142	.104	.141
2	97.5			.257	.239	.211
2B	75.0				.181	.100
2	75.0				.087	.074
2	40.0					
2B	39.5					

Average deviation 0.106 percent or one part in 940

TABLE II—continued

Deviation in Percent of Volumes Observed Less Calculated Using Equation 9. Steam Confined with Mercury

Container No.	250	260	270	280	290	300
2	0.064	0.082	0.093	0.105	0.121	0.137
2B	−.124	−.021	−.117	.002	−.016	−.006
2B	.129	.193	.217	.197	.260	.262
2	.192	.188	.189	.199	.217	.233
2B	.120	.100	.157	.109	.179	.204
2	.049	.041	.058	.072	.085	.110
2			−.035	−.098	−.051	.014
2B			−.014	−.029	−.010	−.007

Average deviation 0.106 percent or one part in 940

TABLE III

Deviation in Percent of Volumes Observed Less Calculated Using Equation 9. Steam Confined with Liquid Water (Parts per 1000 on the Pressure)

Container No.	Vol. cc./g.	260	270	280	290	300	310	320	330
2B	50	−.41		−.49		−.71		+.00	
Cap.	40		−.26	−.35		−.70		+.04	
Heater	30				−.48	−.55		−.05	
Used	20							+1.15	
1B	20						+.31	+.63	+.61
1B	17.5							+.47	+.60
1B	15.0								+.47
1B	12.5								
1B	10								
1B	7.5								

Container No.	340	350	360	370	380	400	420	440	460
2B	−.01		−.44		−.08	−.32	−.32	−.29	−.58
Cap.	+.03		.00		−.04	−.21	−.05	−.01	−.24
Heater	−.05		+.13		+.13	+.22	+.15	−.15	−.25
Used	−.28		+.03		+.18	+.40	+.27	−.04	−.33
1B	+.41	+.03	−.17		+.06	−.44	+.21	+.56	+.41
1B	+.28	+.13	−.14		−.07	−.27	+.07	+.53	+.41
1B	+.28	+.26	−.18		−.18	−.17	+.26	+.37	+.31
1B	−.18	+.05	+.05	−.02	−1.52	−.24	+.07	+.07	+.07
1B		−.74	−.52	−.18	+.14	−.01	+.11	+.02	−.02
1B			+1.16	−1.64	−1.69	−.66	+.06	−.36	−.57

Average deviation 2.64 parts per 10000

The differences between the computed and observed volumes based on an equation similar to Equation 9 but of slightly different form involving three more constants were given in Table II of Mechanical Engineering for February 1934. Since the earlier equation was published the measurements of $\left(\frac{\Delta H}{\Delta p}\right)_T$ to 60° C by Doctor Collins became available and the results were used in a re-correlation of all the steam data.

A computation of the volumes corresponding to the pressures and temperatures measured by Knoblauch, Linde and Klebe shows slightly better agreement with the observed volumes than was exhibited in Table I of the 1934 article referred to above. The present average deviation using Equation 9 for the whole range of 56 points is 0.142 percent as compared with 0.149 percent using the earlier equation. The actual numbers for six volumes are given in Table IV.

TABLE IV

DEVIATIONS OF VOLUMES OBSERVED LESS CALCULATED K. L. AND K. DATA
PARTS PER 100

Vol. cc./g.	110	120	130	140	150	160	170	180	190
1598	0.128	0.128	0.116	0.098	0.076				
1122		−.155	−.121	−.096	−.107				
740.5			.109	.113	.091	.069	.061		
389.7						−.035	−.028		
191.0								−.006	+.022

The steam for volume measurements from 150 cc. to 39.5 cc. per gram (Table II) was confined in the containers by means of mercury. Observations were taken to temperatures of 330° but subsequent comparisons with similar measurements where the steam was confined with water made clear that 330 was too high a temperature in the present stage of knowledge pertaining to the physical properties of mercury-water mixtures to permit adequate corrections to be made for the presence of mercury vapor. An important correction is of course that for the vapor pressure of mercury taking account of the effect of the pressure of the steam on the mercury (Poynting effect). The usual treatment proceeds on the assumption that the ideal gas law applies to the vapor (mercury vapor in this instance) and also that the neutral gas exerting a pressure P and the vapor of the liquid form a gaseous mixture for which Dalton's rule is valid. Neither of these assumptions are a sufficiently close approximation[20] to enable the observed steam-mercury pressures to be corrected when the temperature exceeds 300° C.

In the case of the volume measurements where the steam was confined with water the capillary heater above the steam container facilitated measurements made near the saturation pressure. Of course the meniscus, water-steam, was greatly sharpened, but at pressures well below saturation the capillary heater does not play as important a rôle. The closer agreement between the computed volumes and those measured as shown in Table III is due in part to the fact that at higher densities adsorption effects are smaller and moreover the complications due to the presence of mercury were absent. There was also an erratic trend which has not found explanation.

SATURATION STEAM VOLUMES

A graph wherein pressure and temperature form the ordinates and abscissas will contain the saturation or vapor pressure line with the pressures and temperatures corresponding to the various constant volumes forming nearly straight lines rising from the vapor pressure curve. Each constant volume line drawn through the experimental points may be extrapolated to the vapor pressure to give the saturation pressure and temperature corresponding to the constant volume values.[21] The extrapolation would appear to offer little difficulty because the isometrics exhibit comparatively slight curvature. In the case of steam, however, and possibly the same behavior will prove true for other vapors when correspondingly precise data are available, the curvature increases perceptibly as the isometric passes into contact with the saturation pressure-temperature line.

This characteristic curvature effect in the isometrics can be made more evident by means of a special graph, Fig. 2, wherein the isometric pressures and temperatures are plotted as percentage pressure deviations from linear equations based on a pair of pressures and

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[20] H. T. Gerry and L. J. Gillespie, Phys. Rev. *40*, 269 (1932) have critically considered the data for the vapor pressure of iodine obtained by the gas streaming method. In the paper cited details are given of a method for making an exact computation of the effect of a neutral gas on vapor pressure whereby the deficiencies of Dalton's rule and the ideal gas laws are avoided.

[21] A diagram of this kind will be found in Mech. Eng. *53*, 136 (1931). Fig. 1, and a preliminary set of saturation temperatures for various volumes is given in Table 4 of the same article. These values are, however, superseded by the results given in the present paper.

DEVIATION OF ISOMETRICS FROM LINEARITY

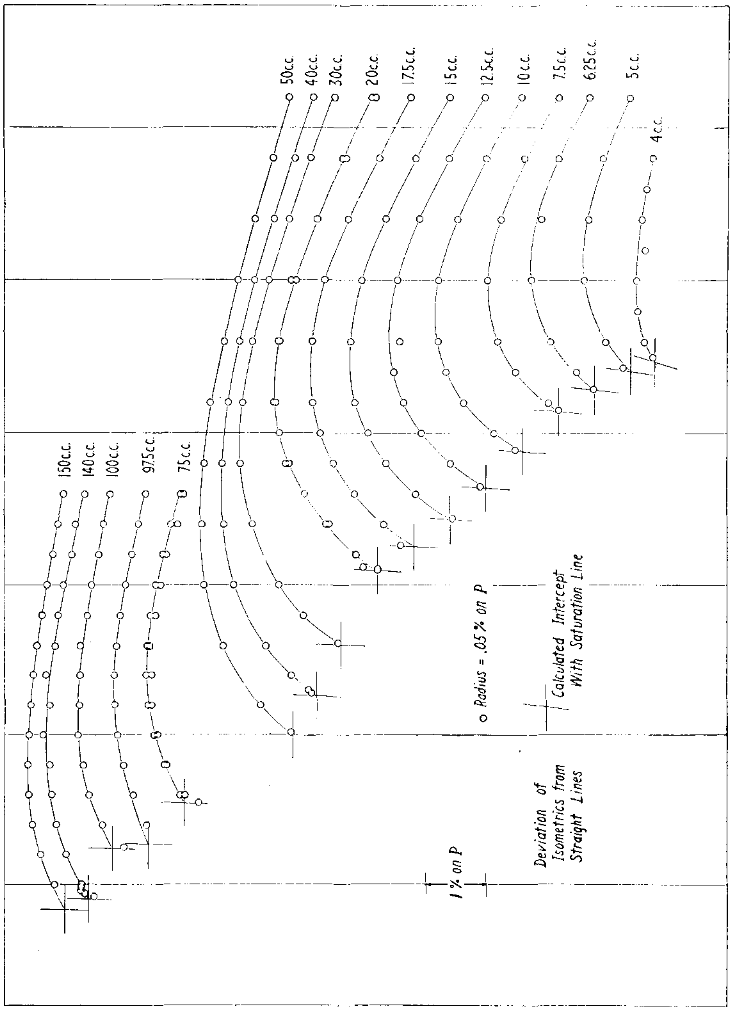

FIGURE 2

temperatures for each isometric. In the figure a different scale has been used for each isometric and the diameter of the circles corresponds in each case to a part in a thousand of the pressures. The figure makes quite evident the increased curvature of the isometric for the first 25 to 50 degrees from the saturation condition. The increased curvature appears to attain a maximum at about 10 to 20 cc. per gram and is less at 4 cc. per gram, although it must be noted that the available range of pressures and temperatures is less.

Where high precision is desired the difficulty of graphical extrapolation appears pronounced. The experience obtained thus far indicates the superiority of computing values of B ($B = v - RT/p$) from the observed data and representing them by means of a smoothing function such as, for example, the analytical expression for B in Equation 9. Once successive trials have indicated a suitable smoothing function, a least square representation of the isometric pressures and temperatures may be secured and the corresponding saturation values determined with a precision related to the suitability of the smoothing function. Table V gives a survey of the saturation volumes, column 1 of which gives the graphically extrapolated saturation temperature corresponding to the volumes of column 2. Column 3 gives the specific volume computed from the equation of state using the temperatures given in column 1 and the corresponding saturation pressures,[22] while the fourth column contains the volumes computed by means of a special equation for saturation volumes as follows:

$$v_{sat} = \frac{4.5550 \times T_s}{p_s} + B_o - \Delta B_s$$

$$\Delta B_s = \frac{1}{(0.17119 + 0.032\, x^{1/3} + 4.73 \cdot 10^{-4} x)\,(1 + 0.14 \cdot 10^{-24}\, x^{10})} \qquad (10)$$

$$x = (374.11 - t_s); \quad T_s = (273.16 + t_s); \quad B_o \text{ from Equation 9}$$

The table indicates that the saturation temperatures as determined by graphical means are in nearly all cases (isometrics for 17.5, 12.5, and 10.0 are exceptions) too low relative to the saturation temperatures that would be deduced by the equation of state using the experimental isometric volumes. The saturation temperatures obtained through the use of the equation of state are however assumed to be the more reliable in view of the apparently precise smoothing of the isometric data. To give reliable saturation volumes, the analytical method using empirical smoothing functions requires isometric pressures and temperatures close to saturation. The steam measurements were in all cases as Fig. 2 indicates, taken as close to saturation as seemed practical and in several instances (140 cc. and 75 cc.) a number of observations were made within a fraction of a degree of the saturation temperature. A difficulty arises nevertheless since adsorption tends to its largest effect near saturation. The larger the specific volume or the lower the temperature, the greater the relative importance of errors due to adsorption on the walls of the container, and the isometric pressure will tend in consequence to be low near saturation. The whole subject has been given considerable thought over a period of several years during which many variations of the graphical and analytical methods were investigated. We believe the saturation values given by the equation of state the best that can be obtained at this time with the data available.

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[22] L. B. Smith, F. G. Keyes and H. T. Gerry, Proc. Am. Acad. Arts and Sci., *69*, 137 (1934). Equation (1) for vapor pressures was used.

TABLE V

GRAPHICALLY EXTRAPOLATED ISOMETRICS AND COMPUTED SATURATION VOLUMES

t_s	Isometric vol. cc./g.	v_{1s} Eq.(9)	v_{1s} Eq.(10)
191.90	150	150.25	150.25
195.26	140	140.11	140.11
211.98	100	100.32	100.33
213.33	97.5	97.727	97.738
227.30	75	75.112	75.118
250.00	50	50.043	50.061
263.05	40	40.004	40.018
280.19	30	30.019	30.028
304.64	20	20.017	20.018
312.70	17.5	17.484	17.486
321.56	15	15.023	15.028
332.03	12.5	12.477	12.474
343.89	10	9.959	9.978
357.11	7.5	7.537*	7.502
364.05	6.25		6.253
370.53	5		4.975
373.40	4		4.127

* Saturation Volumes smaller than 10 cc. per gram are not accurately given by the Equation of state (9).

The equation of state is valid to about 10 cc. per gram while the special equation 10 is valid over the entire range or at least to a saturation volume of 4 cc. per gram. It is not believed however that the precision for volumes smaller than 10 cc. per gram is as satisfactory as for larger volumes. The method by which the special equation (10) was constructed is as follows:

The saturation volumes, temperatures and pressures consistent with the equation of state 9, the corresponding values from the graphical process, and the saturation pressures as given by the formula of Part II, were used to compute ΔB_s from the relation $\left(\frac{RT_s}{p_s} + B_o - v_s\right)$. The magnitude ΔB_s may evidently be represented as a function of $(374.11 - t_s)$, designated by x, or of p_s. The former independent variable was selected. By trial it was found that the reciprocal of ΔB_s tended to a limiting value as x moved to zero. The limiting value chosen was 0.17119 and the function $(\Delta B_s)^{-1} - 0.17119)\, x^{-1/3}$ appeared to vary linearly with $x^{2/3}$ when all available saturation data obtained by the graphical process were used. A straight line represented by $0.032 + 4.73 \cdot 10^{-4}\, x^{2/3}$ appeared to be satisfactory for representing the data to temperatures as low as 250° C. Comparisons were then made between the specific volumes computed with this provisional special equation and the saturation values below 200° C computed by means of the equation of state 9. From a consideration of the differences between the saturation volumes given by the provisional special equation and the saturation volumes computed from the equation of state, the term $(1 + 0.14 \times 10^{-24} x^{10})$ was devised to represent the quantity

$$[1 + (v_s \text{ provisional} - v_s)\,(0.17119 + 0.032x^{1/3} + 4.73 \times 10^{-4}x)]^{-1}.$$

The final special equation for v_s is therefore 10 above.

In Table VI the saturation volumes are given for each ten degrees from zero computed from Equation (10). Below 100° the values of the saturation volumes correspond to saturation pressures given by the following pressure-temperature relation:

$$\log_{10} p^{Int.\ Atm.} = -\frac{3142.305}{(t + 273.16)} - 8.2 \log T + 2.4804 \times 10^{-3}T + 28.5847521 \quad (11)$$

Above 100 degrees the corresponding saturation pressures are given by equation (1) of paper Part II as already stated. The formula (11) reproduces the experimental values of Scheel and Heuse more satisfactorily than formula (2) of the latter report with respect to the

TABLE VI

SATURATION VOLUMES OF STEAM COMPUTED FROM EQUATION (10) USING SATURATION PRESSURES OBTAINED FROM EQUATION (1), PART II
COMPARISONS WITH SIMILAR VOLUMES BY OSBORNE, STIMSON AND GINNINGS

t	v_s cc./g. K.S.G.	v_s cc./g. O.S.G.	t	v_s cc./g. K.S.G.	v_s cc./g. O.S.G.
0	2.0630:5	2.0643:5	200	1.2718:2	1.2716:2
10	1.0641:5	1.0650:5	210	1.0424:2	1.0425:2
20	5.7824:4	5.7872:4	220	8.6070:1	8.6060:1
30	3.2922:4	3.2942:4	230	7.1483:1	7.1470:1
40	1.9543:4	1.9550:4	240	5.9684:1	5.9674:1
50	1.2045:4	1.2047:4	250	5.0061:1	5.0054:1
60	7.6783:3	7.6788:3	260	4.2149:1	4.2145:1
70	5.0463:3	5.0464:3	270	3.5593:1	3.5593:1
80	3.4092:3	3.4094:3	280	3.0122:1	3.0124:1
90	2.3615:3	2.3617:3	290	2.5522:1	2.5527:1
100	1.6732:3	1.6733:4	300	2.1625:1	2.1634:1
110	1.2101:3	1.2103:3	310	1.8300:1	1.8312:1
120	8.9165:2	8.9179:2	320	1.5438:1	1.5454:1
130	6.6821:2	6.6831:2	330	1.2952:1	1.2968:1
140	5.0853:2	5.0861:2	340	1.0764:1	1.0776:1
150	3.9246:2	3.9250:2	350	8.802	8.798
160	3.0676:2	3.0678:2	360	6.984	6.941
170	2.4255:2	2.4256:2	270	5.093	4.949
180	1.9380:2	1.9380:2	372	4.608	
190	1.5632:2	1.5631:2	374	3.693	
			374.11	3.1975	

The digits following the numbers are the indices of 10 forming the factors by which the numbers are to be multiplied. Thus, 2.0630:5 means that the volume is 2.0630 × 10^5, or 206300.0 cc./g.

values from 0 to 30 degrees. It is also much simpler than Equation (5) of the earlier report, although this equation appears to be a satisfactory smoothing function over the same temperature range.

Comparisons of the present saturation volumes with those of other investigators is not easy. As a matter of fact, there has been developed only recently a method of direct measurement capable of giving highly precise values,—the general calorimetric method of Osborne, Stimson and Fioch.[23] Saturation values are of course given in the various steam tables but the most recent contain values derived from latent heats of evaporation through the Clapeyron equation. Such values are not particularly interesting for comparison purposes without a full discussion of the sources and comparative merits of different latent heats. Moreover the most recent experimental results of our colleagues in the steam investigation are now sufficiently complete to indicate the accord between two independent methods of measurement. The Osborne, Stimson and Ginnings values given in the 1935 paper cited, extend from 0° to 370° and consist of directly measured values of $L\frac{v_1 - v_2}{v_1}$[24] designated as γ. With reliable values of dp/dT from the vapor-pressure relation v_1 is given by $\gamma / T\frac{dp}{dT}$ using the Clapeyron equation. The columns of specific volumes in Table VI headed O. S. G. were deduced from the experimentally determined γ values using the $T\frac{dp}{dT}$ values taken from the 1933 report of Osborne, Stimson, Fioch and Ginnings.[25] The agreement appears to be satisfactory to 350° and constitutes a further indication of the accord between the results of the independent investigations.[26] Our specific volumes above 350° depend on an extrapolation of saturation volumes by Equation 10 which is based on values deduced from the superheat volumes through the equation of state (9) valid to 10 cc. per gram or saturation temperatures somewhat higher than 340°. It is true that in carrying out the extrapolation the graphically deduced saturation temperatures corresponding to volumes 7.5, 6.25, 5 and 4 cc. per gram were available but the graphical extrapolation as has been suggested may not be particularly reliable and becomes more uncertain as the critical region is approached. The values due to Osborne, Stimson and Ginnings in column 3 of Table VI are considered the more reliable at 350° and higher temperatures.

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[23] Osborne, Stimson and Fioch, U. S. Bur. Stand. Jour. Res. *5*, 411 (1930). Osborne, Stimson and Ginnings, Mech. Eng. *57*, 162 (1935).

Table VII contains data for the specific volumes of steam from 100° to 550° and to 400 kg./cm.^{2} computed by using equation (9) to 10 cc. per gram and for smaller volumes by graphical methods. Saturation volumes at the various temperatures are given in brackets.

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[24] L represents the heat of evaporation, v_1 the saturated vapor, and v_2 the saturated liquid specific volume.

[25] Osborne, Stimson, Fioch and Ginnings, U. S. Bur. Stand. Jour. Res. *10*, 155 (1933).

[26] The Osborne, Stimson, Fioch and Ginnings values of $T\frac{dp}{dT}$ are in excellent agreement from 100 to 360° with similar values obtained by Smith, Keyes and Gerry in their Part II of the Steam Research Program. Differences for the most part are less than one in three thousand.

TABLE VII

Steam Volumes in Units of 10^3 cc./g.

$\frac{Kg}{cm^2}$	100°	150°	200°	250°	300°	350°	400°	450°	500°	550°
1	1.7296	1.9754	2.2158	2.4541	2.6913	2.9279	3.1641	3.4001	3.6360	3.8718
5			.4338	.4841	.5332	.5816	.6296	.6774	.7250	.7725
10			.2104	.2376	.2633	.2882	.3127	.3370	.3611	.3851
25				.08899	.1011	.1121	.1226	.1327	.1427	.1526
50					.04641	.05312	.05905	.06460	.06992	.07510
100						.02303	.02705	.03041	.03345	.03632
150						.01198	.01610	.01890	.02125	.02336
200							.01031	.01305	.01511	.01687
250							.006366	.009456	.01139	.01296
300							.003022	.006979	.008898	.01035
350							.002173	.005168	.007108	.008494
400								.003858	.005774	.007109

THE ENTHALPY OF STEAM

The enthalpy, H, may be conveniently derived by starting with the differential equation $\left(\frac{\partial H}{\partial p}\right)_T = v - T\left(\frac{\partial v}{\partial T}\right)_p = \left(\frac{\partial v\tau}{\partial \tau}\right)_p$ where τ represents T^{-1}. Using the equation of state (9) it is evident that the right hand member becomes $\left(\frac{\partial B\tau}{\partial \tau}\right)_p$. Integration gives the following relation:

$$H = H_o + \int_o^p \left(\frac{\partial B\tau}{\partial \tau}\right)_p dp \tag{12}$$

where H_o is a pure temperature function, the nature of which is evident upon differentiating (12) with respect to temperature subject to the condition that p decreases to zero. We then find:

$$\left(\frac{\partial H_o}{\partial T}\right)_{p \longrightarrow o} = C_p{}^\circ \tag{13}$$

where $C_p{}^\circ$ is the heat capacity steam would have at very low, in the limit zero, pressure; a pure temperature function. The equation (12) may now be written:

$$H = h_o + \int_{T_o}^{T} C_p{}^\circ \, dT + \int_o^p \left(\frac{\partial B\tau}{\partial \tau}\right)_p dp \tag{14}$$

and h_o is a constant to be determined when a condition of reference is selected.

The second term of the right hand member of (12) is readily obtained from the B form given under (9) leading to an equation which may be written as follows:

$$H = h_o + \int_{T_o}^{T} C_p{}^\circ \, dT + \frac{\partial B_o\tau}{\partial \tau} p + 1/2 \frac{\partial (B_o\tau)^2 \cdot g_1(\tau)}{\partial \tau} p_2$$
$$+ 1/4 \frac{\partial (B_o\tau)^4 \cdot g_2(\tau)}{\partial \tau} p^4 - 1/13 \frac{\partial (B_o\tau)^{13} \cdot g_3(\tau)}{\partial \tau} p^{13} \tag{15}$$

The value of $C_p{}^\circ$ is evidently of great importance but unfortunately the heat capacity of a gas or vapor is very difficult to measure accurately although great ingenuity has been exercised in the attempt to secure reliable values. H. N. Davis[27] reduced 178 of the older determinations of Knoblauch and Jacob[28] by means of the Joule-Thomson data obtained by Davis and Kleinschmidt[29] obtaining values of C_p° for temperatures from 135 to 350°. The fundamental equation required for the analytical reduction is as follows:

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[27] H. N. Davis, Mech. Eng., *46*, 85 (1924).

$$C_{p_0} = C_p + \int_0^p \mu \left(\frac{\partial C_p}{\partial T}\right)_p dp + \int_0^p C_p \left(\frac{\partial \mu}{\partial T}\right)_p dp \qquad (16)$$

where C_p is the heat capacity at pressure p and μ is the Joule-Thomson coefficient. The results of the computations led to the following equation for C_p° valid from 140 to 350°.

$$\underset{Int.\ j.}{C_p^\circ} = 1.7435 + 8.54 \cdot 10^{-4} t \qquad (17)$$

A reformulation of the same specific heat data including results obtained by Regnault and by Brinkworth was later undertaken by Professor J. H. Keenan[30] using additional Joule-Thomson data. The following equation resulted from the investigation:

$$\underset{Int.\ j.}{C_p^\circ} = 1.4421 + 1.13 \cdot 10^{-3} t + \frac{121.4}{T} \qquad (18)$$

In a later paper Davis and Keenan[31] again discussed the specific heat data including the recent measurements of Knoblauch and Raisch[32] and Knoblauch and Koch[33] but without altering the equation (18) for C_p°.

H. Hausen[34] published a paper in 1931 in which a formula for C_p° due to Wohl and von Elbe[35] was used in a formulation of the quantity $(C_p - C_p^\circ)$. The formula[36] has a quasi-quantum theoretical basis and is given in the following form:

$$\begin{aligned} C_p^\circ &= \frac{R}{18}\,[4 + E(x_1) + 2E(x_2)] \\ E(x) &= \frac{x^2 e^x}{(e^x - 1)^2}\,; \quad \begin{matrix} x_1 = \Theta_1/T; & \Theta_1 = 2280 \\ x_2 = \Theta_2/T; & \Theta_2 = 5370 \end{matrix} \end{aligned} \qquad (19)$$

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[28] Knoblauch and Jacob, Forscharb. Berlin, Heft 35 and 36, 109 (1906).

[29] Davis and Kleinschmidt, Mech. Eng. *45*, 165 (1923).

[30] J. H. Keenan, Mech. Eng., *48*, 144 (1926).

[31] Davis and Keenan, Mech. Eng. *51*, 922 (1929).

[32] Knoblauch and Raisch, Zeit. Ver. Deutsch. Eng. *66*, 418 (1922).

[33] Knoblauch and Koch, Zeit. Ver. Deutsch. Eng. *72*, 1733 (1928).

[34] H. Hausen, Forschung auf dem Gebiete des Engeneurwesens, *2*, 319 (1931).

[35] Wohl and von Elbe, Zeit. für Phys. Chem. (B) *5*, 241 (1929).

[36] See Max Jacob's comments, Engineering, *132*, 684 (1931).

Keyes, Smith and Gerry[37] in 1934 published a formulation of the new volume data of Smith and Keyes[38] which enabled all the new specific heat data,[39] the Joule-Thomson data and the new determinations of the enthalpy of steam by Osborne, Stimson and Fioch to be used for computing $C_p°$, and the following equation was deduced to represent the results:

$$\underset{Int.\,j}{C_p°} = 1.8738 + 3.211 \times 10^{-4}t + 1.488 \times 10^{-9}t^3 \tag{20}$$

In the meantime S. Sugawara[40] had formulated the new steam data and proposed an equation for $C_p°$ based on his computations. His equation follows:

$$\underset{Int.\,j}{C_p°} = 1.9088 + 9.2931 \times 10^{-7}t^2 \tag{21}$$

In view of the almost insuperable difficulty of measuring the low pressure heat capacities of gases with high precision, there can be little question that the most reliable method of obtaining an accurate knowledge of $C_p°$ is through the use of band spectrum data. Until recently however[41] a satisfactory analysis of the rotation-vibration band spectrum data for water vapor had not been carried out. Some further work remains to be done but sufficient is known to permit calculation of reliable thermodynamic properties and the required computations have recently been made by A. R. Gordon[42] leading to values of the entropy and heat capacity for water vapor in the hypothetical ideal gas state. It is believed that Gordon's values, extending from 25° to 1200° are the most satisfactory existing data and these $C_p°$ values will be used in completing the enthalpy equation. The following empirical form[43] suffices for the temperature range of interest.

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[37] Keyes, Smith and Gerry, Mech. Eng. *55*, 87 (1933).

[38] Smith and Keyes, Mech. Eng., *54*, 123 (1932).

[39] W. Koch, Forschung auf dem Gebiete des Engenieurwesens, *3*, 1 (1932).

[40] S. Sugawara, Mem. College of Eng., Kyoto Imp. Univ. *7*, 17 (1932).

[41] Mecke, Zeit. f. Physik, *81*, 313 (1933). Baumann and Mecke, Zeit. f. Physik, *81*, 445 (1933). Freudenberg and Mecke, Zeit. f. Physik, *81*, 465 (1933).

[42] A. R. Gordon, J. Chem. Phys. *2*, 65 (1934).

[43] We owe this formula to Professor J. H. Keenan. The formulation based on the Gordon values and used in computations for the Third International Steam Conference was $C_p° = 1.798 + 0.00148 \dfrac{T^2}{T + 2000}$.

$$C_{p\,Int.\,j.}^{\circ} = 1.47198 + 7.5566 \times 10^{-4} T + \frac{47.8365}{T} \qquad (22)$$

$$\int_{273.16}^{T} C_p^{\circ}\, dT = 1.47198\,(T - 273.16) + 3.7783 \times 10^{-4}\,(T^2 - 273.16^2) + 110.14757 \log_{10} \frac{T}{273.16}$$

Table VIII gives a survey of the values of C_p° from the sources referred to above for temperatures 100, 200, 300, 400.

TABLE VIII

COMPARISON OF C_p° VALUES FROM VARIOUS SOURCES

t	J. H. Keenan 1926 Eq. 18	K.S.G. 1934 Eq. 20	Wärmetabellen	W.von E.	Sugawara	A. R. Gordon	A.R.G. (Keenan)
100	1.8804	1.9074		1.8844	1.9181	1.8820	1.8821
200	1.9247	1.9500	1.9333	1.9352	1.9460	1.9305	1.9306
300	1.9929	2.0106	1.9996	1.9947	1.9914	1.9887	1.9886
400	2.0745	2.0982	2.0442	2.0573	2.0575	2.0517	2.0517

We will evaluate the enthalpy constant using the enthalpy of steam, at 100° and saturation pressure, as determined by Osborne, Stimson and Fioch; our colleagues in the steam investigation. The enthalpy is recorded under the convention that the enthalpy of the liquid at zero and saturation is zero. Of course zero is the temperature of equilibrium of water, ice under a pressure of one atmosphere whereas the triple point of water is 0.01° C and should preferably be taken as the reference temperature for enthalpy and entropy. We will take for the enthalpy of saturated steam at 100° and one international atm. the quantity 2675.35 Int. joules (H_{s1}^{100}). Making use of the Gordon C_p° values as represented by Keenan's empirical formula (22) and the equation of state (9) to evaluate the remaining integral of (14), we find for h_o the number 2502.36. The equation (15) may now be written in the following abbreviated form, using A, B, C, D to represent the coefficients of pressure.

$$\underset{(Int.\,j.)}{H_{s1}} = 2502.36 + \int_{T_o}^{T} C_p^{\circ}\, dT + Ap + Bp^2 + Cp^4 - Dp^{13} \qquad (15A)$$

In Table IX the values of enthalpy corresponding to the saturated vapor state, H_{s1}, are tabulated from 0 to 350. In the second column the latent heats are given computed by means of the Clapeyron

TABLE IX

Latent Heats of Evaporation and Enthalpy of Steam for the Saturated Vapor

t	$L^{Clap.}$	$L^{O.S.G.}$	$H_{s1}^{Eq.\ 15A}$	$H_{s1}^{O.S.G.}$
0	2500.15	2497.77[a]	2501.86	2497.77[a]
10	2476.18	2475.21[a]	2520.11	2517.23[a]
20	2452.42	2452.38[a]	2538.24	2536.21[a]
30	2428.88	2429.27[a]	2556.27	2554.86[a]
40	2405.14	2405.85[a]	2574.17	2573.19[a]
50	2381.37	2382.10	2591.86	2591.21
60	2357.40	2357.97	2609.27	2608.88
70	2333.05	2333.41	2626.39	2626.16
80	2308.18	2308.36	2643.33	2643.03
90	2282.75	2282.79	2659.49	2659.44
100	2256.64	2256.59	2675.35	2675.35
110	2229.80	2229.69	2690.65	2690.67
120	2202.18	2202.05	2705.33	2705.42
130	2173.68	2173.52	2719.30	2719.45
140	2144.19	2144.02	2732.50	2732.73
150	2113.60	2113.40	2744.84	2745.14
160	2081.78	2081.61	2756.24	2756.64
170	2048.61	2048.46	2766.59	2767.11
180	2013.95	2013.83	2775.81	2776.44
190	1977.63	1977.54	2783.81	2784.53
200	1939.52	1939.44	2790.46	2791.25
210	1899.00	1899.36	2795.65	2796.51
220	1857.10	1857.07	2799.22	2800.13
230	1812.37	1812.34	2801.13	2801.98
240	1764.95	1764.92	2801.11	2801.88
250	1714.52	1714.55	2799.00	2799.69
260	1660.74	1660.85	2794.58	2795.13
270	1603.18	1603.44	2787.57	2788.00
280	1541.34	1541.83	2777.63	2777.96
290	1474.57	1475.39	2764.33	2764.64
300	1402.08	1403.33	2747.05	2747.56
310	1322.80	1324.52	2725.06	2725.99
320	1235.22	1237.33	2697.32	2698.89
330	1137.14	1139.30	2662.51	2664.69
340	1024.99	1026.35	2618.44	2620.76
350	892.15	891.12	2562.58[a]	2562.48
360	724.73	717.2	2491.27[a]	2479.9
370		438.2		2332.7

[a] Extrapolated.

All values are in Int. joules per gram of steam using the factor 1.0003 for the ratio of the absolute to the international joule. The factor used to convert cc. atm. to int. j. was 0.101295.

equation, using the values of v_1 from Table VI, dp/dT and v_2 from parts II and III of these reports.[44]

The corresponding values of latent heats and enthalpy given by Osborne, Stimson and Ginnings[45] are also listed in columns three and five. The agreement is quite satisfactory with the exception of the values above 340°. The saturation volumes above 350°, as stated in discussing Table VI, are difficult to obtain precisely by graphical extrapolation of the isometric data and the larger latent heats in column two are due to the fact that our larger volumes were used in the computation. In a later paper the isometrics for volumes smaller than 10 cc. per gram will be represented analytically thereby making it possible to carry out the extrapolation with greater precision.

LATENT HEATS BELOW FIFTY DEGREES

It will be noted that the enthalpy at 0° computed from the Clapeyron relation and from the H_{s1} equation differs by 1 part in 1460, a quantity that is larger than is desirable in view of the accord at higher temperatures. Unfortunately there are few data available in this region. The lowest temperature for which latent heats have been measured with modern equipment[46] is 50° where the measured value 2382.1 is to be compared with 2381.37 from column two; a difference of 1 part in 3300. The difference cannot all be due to an error in the saturation specific volume since the volume given by Osborne, Stimson and Ginnings differs by 1 part in 6000 from that used in the computation. The value of T_o (273.16) used in the present paper is probably in error at most by 1 part in 10000 relative to the true value, while the accord of the international temperature scale with the thermodynamic scale is entirely satisfactory in this region according to a private communication from Professor Beattie, who bases his opinion on many comparisons between his gas and resistance thermometers.[47] The quantity most likely in doubt is the value of $\frac{dp}{dT}$. All values of $\frac{dp}{dT}$ employed below 100° are based on the data of the Physikalisch Technische Reichsanstalt tables of 1909, and the derivatives obtained by Osborne and Myers[48] above 50° differ from the values used in the present paper (derived from equation 11) by 1 in 7400 at most. At 50° the difference is 1 in 12000, dropping to 1 in 2400 at 30° and to 1 in 650 at 0°. In part II of the steam papers some comments were made regarding the difficulty of obtaining derivatives below 50° and further comment may now be made on the basis of the H_{s1} equation from which latent heats may be derived by subtracting at corresponding temperatures the value of H_{s2} due to Osborne, Stimson and Ginnings.

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[44] L. B. Smith and F. G. Keyes, Proc. Am. Acad. Arts and Sci. *69*, 285 (1934); *69*, 137 (1934).

[45] Osborne, Stimson and Ginnings, Mech. Eng. *57*, 162 (1935).

[46] N. S. Osborne, Mech. Eng. *53*, 137 (1931).

[47] This conclusion is also supported by the earlier work of Henning and his coworkers.

To establish the equation (15A) there is available as already stated the Gordon $C_p{}^\circ$ values which we consider the most reliable available. We have also very exact measured values of the liquid enthalpy, which were used in part III to derive values of C_{p2}, the heat capacity for constant pressure for the saturated liquid. Finally there is available the equation of state (9) for steam. It proves of interest to use these data to compute the change of the latent heat with temperature and view the trend of the values below 50°. The significance of any peculiarities of trend in $\dfrac{dL}{dT}$ derives from the relation of the quantity to the vapor pressure, or in our case more immediately to $\dfrac{dp}{dT}$.

It is convenient in computing $\dfrac{dL}{dT}$ to use the following equation:[49]

$$\frac{dL}{dT} = C_{p1} - C_{p2} + \left[\left(\frac{\partial v_1\tau}{\partial \tau}\right)_p - \left(\frac{\partial v_2\tau}{\partial \tau}\right)_p\right]\frac{dp}{dT} \tag{23}$$

where C_{p1} and C_{p2} are the constant pressure heat capacities at saturation pressures. Below 100° $\left(\dfrac{\partial v_2\tau}{\partial \tau}\right)_p$ is small relative to $\left(\dfrac{\partial v_1\tau}{\partial \tau}\right)_p$ (1 part in 186 at 100°)* and may be neglected. C_{p1} is given by the relation $C_{p1} = C_{p1}{}^\circ + \partial/\partial T \displaystyle\int \left(\frac{\partial v_1\tau}{\partial \tau}\right)_p dp$ and C_{p2} has already been given

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[48] N. S. Osborne and C. H. Myers, U. S. Bur. of Standards J. Res. *13*, 1 (1934).

[49] This equation is a new form of a familiar equation. It is exact and may be easily derived from the relation

$$\frac{dL}{dT} = C_{p1} - C_{p2} + L/T - L/v_1 - v_2\left[\left(\frac{\partial v_1}{\partial T}\right)_p - \left(\frac{\partial v_2}{\partial T}\right)_p\right]$$

* Of course far less at lower temperatures.

(Table VIII, part III). Table X gives the computed values of $\frac{dL}{dT}$ and similar quantities derived from the Osborne, Stimson and Ginnings latent heats. From Fig. 3, prepared from the entries in Table X, it is clear that there is a maximum in the computed values at about 15°. Of course it has long been known that a minimum existed in C_{p2} below 50°, and accordingly it is to be expected that the course of the $\frac{dL}{dT}$ curve might exhibit some peculiarity of trend in approximately the same temperature range. The question of the quantitative accuracy of the computed numbers is important. The values for C_{p1} and $\left(\frac{\partial v_1\tau}{\partial \tau}\right)_p$ are computed using the equation of state 9. The values of $\frac{dp}{dT}$ used are not important since they are sufficiently exact for our present purpose. The fraction of $C_{p1}{}^{\circ} - C_{p2}$ due to the equation of state contribution is 0.02 at 0°, 0.044 at 20°, and 0.104 at 50°. It would appear therefore that the numbers should be reliable as to trend and at least approximately correct in magnitude.[50]

Clearly if a maximum exists in the $\frac{dL}{dT}$ relation there must be a corresponding inflection in L as a function of T. The inference is therefore that dp/dT will exhibit a related peculiarity in about the same region and if dL/dT could be accurately represented as a function of temperature along with $T\frac{dp}{dT}B$[51] it should be possible, in principle, to carry out the required integrations and obtain the relation between saturation pressure and temperature subject to the condition that L and p are known at 100°. In practice this has proven to be difficult owing to the large number of terms which arise. It may appear

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[50] An empirical equation representing $\frac{dL}{dT}$ is as follows:

$$\frac{dL}{dT} = \left(-\,2.390 + 4.038\cdot 10^{-3}t - 1.3584\cdot 10^{-4}t^2 + 26.6038\frac{t^2}{T^2} - 2.3128\cdot 10^6\frac{t^2}{T^4}\right) I.j.$$

[51] From the Clapeyron equation and the equation of state, neglecting v_2. we find

$$T\frac{dp}{dT}(v_1 - v_2) = L = RT^2\frac{d\log p}{dT} + T\frac{dp}{dT}B = \int\frac{dL}{dT}dT$$

TABLE X

VALUES OF $\frac{dL}{dT}$ COMPUTED USING EQUATION 23

t	$-\frac{dL}{dT}$ *Eq.* 23[52]	$-\frac{dL}{dT}$[53]
0	2.390	
10	2.366	
20	2.366	2.291
30	2.378	2.326
40	2.398	2.358
50	2.421	2.393
60	2.452	2.434
70	2.491	2.480
80	2.532	2.530
90	2.570	2.587
100	2.621	2.654

simpler to evaluate $\frac{dp}{dT}$ using the values for v_1 from Table VI and L from the H_{s1} equation. This procedure, however, leads to no more information and the values of v_1 are of course computed from the equation of state using pressures given by the vapor pressure equation 11 so that the $\frac{dp}{dT}$ values obtained by this calculation would not be independent of the assumed vapor pressure values.

We believe it best to postpone further consideration of this interesting subject until exact data on latent heats over the region of interest become available, and possibly also the results of a special investigation of the vapor pressures of water. Before leaving the subject it is worth noting that the successive differences in $T \log p$ for 5° intervals using the Reichsanstalt vapor pressures indicate a maximum in the differences. The numbers have been used to construct figure (4).

The discussion and intercomparison of the older body of latent heat measurements has been critically carried out by one of our colleagues

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[52] The values in this column could have been derived from the H_{s1} equation 15A diminished by H_{s2}. Because of the maximum in $\frac{dL}{dT}$ it is simpler to proceed by the use of Eq. 23.

[53] Computed from the latent heats of Osborne, Stimson and Ginnings using the Rutledge method for derivatives (Phys. Rev. *40*, 262, 1932).

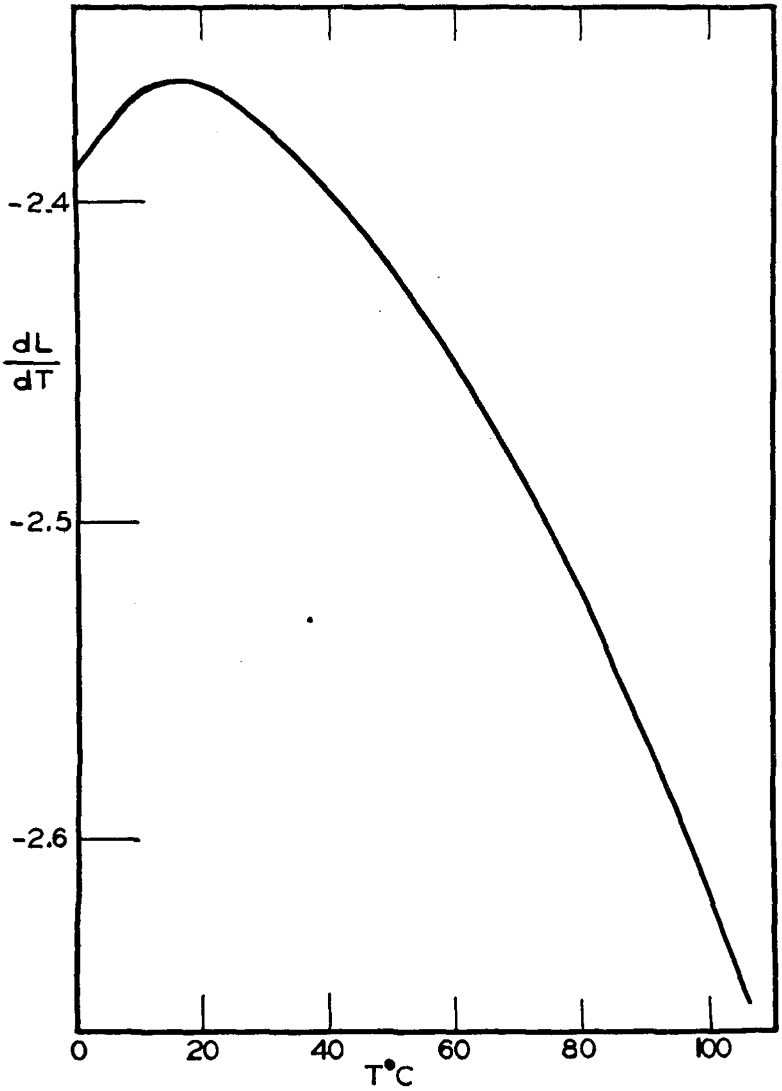

Figure 3

in the steam program of research in a recent publication.[54] It was shown that the older data were in remarkably good agreement with the new measurements,[55] and few of the determinations deviated more than one part in five hundred. The latest estimates of the latent heats below 50° by our colleagues impairs somewhat the earlier very striking agreement in this region, otherwise the accord is on the whole very good within the limits stated. Especially notable is the accord of Carlton-Sutton's value 2256.6 I. j.; Richards and Mathew's, 2256.5; Mathew's, 2255.2; and Henning's, 2255.7 with the present figure 2256.6. The only available determination at zero is apparently too low, the 2490.6 I. j. due to Dieterici.

Later important determinations of latent heats by our German Colleagues in the steam investigation, Jakob[56] and Jakob and Fritz[57] may be viewed as a continuation and extension of the earlier work of Henning, who, nearly thirty years ago, reached a temperature of 180°. The final comparison of these excellent results will be postponed to a later paper. The agreement of the computed latent heats with the new values is, however, quite satisfactory.

THE DERIVED ENTHALPY FOR SUPERHEATED STEAM

During the course of the steam investigation preliminary experimental results for the enthalpy of superheated steam have been privately communicated by our English and Czechoslovakian colleagues. We have also had the privilege of seeing the results of Doctor W. Koch's computations of enthalpy based directly on his measurements of superheated steam. The latter data were particularly interesting because no assumed values of $C_p{}^\circ$ are involved, whereas equation (15A) depends directly upon the Gordon $C_p{}^\circ$ values. The general accord of the enthalpy computed from 15A with the experimental data and with Doctor Koch's deduced values is gratifying, and final comparisons must await full publication of the independent investigations, It may also be necessary finally to have further information on the magnitude of the differences in the international and thermodynamic temperature scales. Should the latter differences prove to be large it will be necessary to reformulate the equation of state for steam and recompute the derived quantities.

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[54] E. F. Fioch, Trans. Am. Soc. Mech. Eng., Fuels and Steam Power, *52*, 231 (1930).

[55] Osborne, Stimson and Fioch, U. S. Bur. Stand. J. Res. *5*, 411 (1930). Osborne, Stimson and Ginnings, Mech. Eng., *57*, 162 (1935).

[56] Max Jakob, Forschungsarbeiten Ver. Deutsch. Eng., *310*, 9 (1928).

[57] Max Jakob and W. Fritz, Zeit. Ver. Deutsch. Eng., *73*, 629 (1929).

TABLE XI

ENTHALPY VALUES FOR STEAM

p^{atm}	$p^{\frac{kg.}{cm^2}}$	100	150	200	250	300	350	400	450	500	550
1		(2675.35)	2776.22	2874.79	2973.43	3072.94	3173.67	3275.81	3379.48	3484.72	3591.58
	1	2675.80	2776.46	2874.94	2973.54	3073.02	3173.73	3275.86	3379.52	3484.76	3591.61
5			(2744.84)	2854.71	2959.95	3063.11	3166.10	3269.74	3374.48	3480.51	3587.97
	5			2855.58	2960.50	3063.51	3166.40	3270.14	3374.68	3480.68	3588.12
10				2826.07	2941.79	3050.26	3156.37	3262.04	3368.16	3475.21	3583.44
	10			2828.06	2944.01	3051.11	3157.00	3262.52	3368.57	3475.55	3583.74
25				(2790.46)	2877.66	3008.14	3125.45	3238.02	3348.74	3459.05	3569.70
	25				2881.51	3010.53	3127.17	3239.34	3349.80	3459.91	3570.43
50					(2799.00)	2921.77	3067.51	3194.99	3314.84	3431.26	3546.30
	50					2928.04	3071.51	3197.87	3317.08	3433.03	3547.83
100						(2747.05)	2918.67	3095.64	3240.77	3372.45	3497.70
	100						2930.01	3102.67	3245.80	3376.36	3500.80
150							2677.85	2971.96	3156.96	3309.40	3446.65
	150						2710.39	2985.28	3165.64	3315.21	3451.67
200							(2562.58)	2809.41	3060.81	3240.77	3393.09
	200							2833.55	3074.19	3249.86	3400.11
250								[2550.33]	2948.90	3166.89	3336.95
	250							[2607.05]	2968.32	3179.21	3346.15

[59] The values in parentheses are the values of enthalpy at saturation for the respective temperatures. The bracketed value under 400° corresponds to a volume less than 10 cc. per gram and is not considered on a par with the other values.

The results of the present computations of enthalpy are given in Table XI for even pressures in standard atmospheres and kilograms per cm.^{2} from 100° to 550°. In Table XII will be found the coefficients A, B, C and D of Equation 15A for pressures expressed in the two pressure units appearing in Table XI.

Some comparisons of the values of the enthalpy as given in Table XI with similar values from recent steam tables[58] are of interest.

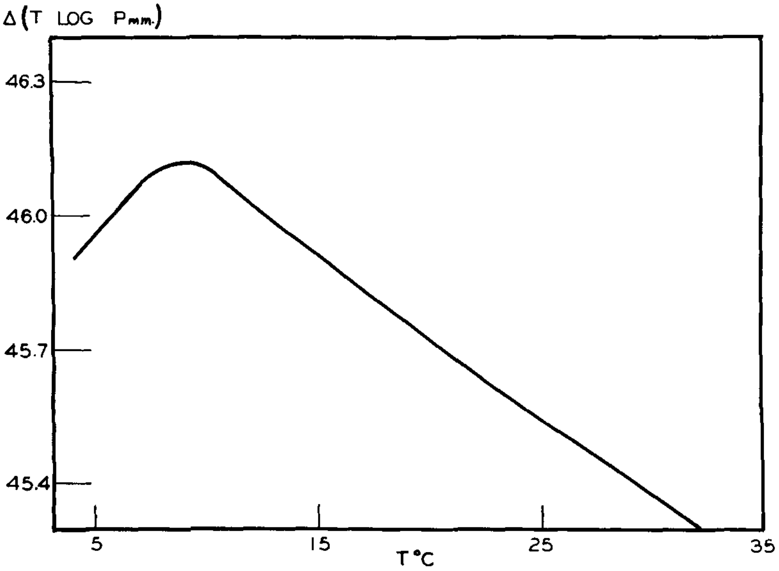

FIGURE 4

The following table, XIII, gives the differences in parts per thousand between the values of enthalpy in the latest steam tables of Knoblauch, Raisch, Hansen and Koch and those in Table XI. It is evident that the values in the latter table are increasingly smaller than the K. R. H. and K. values as higher pressures and higher temperatures are approached. The computed values are in better agreement with the Keenan steam table values as might be anticipated in view of the

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[58] O. Knoblauch, E. Raisch, H. Hansen and W. Koch, Tabellen und Diagramme für Wasserdampf, Berlin, 1932. Herbert Moss, The Revised Callendar Steam Tables, London, 1931. Joseph H. Keenan, Steam Tables and Mollier Diagram, New York, 1930.

TABLE XII

VALUES OF THE COEFFICIENTS OF PRESSURE IN THE ENTHALPY EQUATION 15A

(All values are in Int. joules per gram of steam)

	−A	−B	−C	D	
100	12.5735	9.7886:−1	2.9957:− 3	negligible	atm.
	12.1691	9.1692:−1	2.6285:− 3	"	kg./cm.^{2}
150	7.1061	2.3680:−1	2.0983:− 4	"	
	6.8776	2.2182:−1	1.8411:− 4	"	
200	4.5676	7.4531:−2	2.3550:− 5	6.5570:−19	
	4.4208	6.9814:−2	2.0664:− 5	4.2871:−19	
250	3.2024	2.8060:−2	3.5977:− 6	3.3255:−22	
	3.0994	2.6285:−2	3.1568:− 6	2.1742:−22	
300	2.3870	1.2001:−2	6.7363:− 7	4.1496:−25	
	2.3103	1.1242:−2	5.9107:− 7	2.7131:−25	
350	1.8608	5.6384:−3	1.4314:− 7	9.9183:−28	
	1.8009	5.2816:−3	1.2560:− 7	6.4847:−28	
400	1.5002	2.8435:−3	3.2161:− 8	3.1429:−30	
	1.4519	2.6635:−3	2.8219:− 8	2.0549:−30	
450	1.2412	1.5142:−3	6.9325:− 9	−1.3387:−32	
	1.2013	1.4184:−3	6.0829:− 9	−8.7526:−33	
500	1.0480	8.4112:−4	1.0959:− 9	−1.5184:−33	
	1.0143	7.8789:−4	9.6158:−10	−9.9275:−34	
550	0.8994	4.8282:−4	−1.2859:−10	negligible	
	0.8705	4.5225:−4	−1.1283:−10	"	

TABLE XIII

ENTHALPY DIFFERENCES BETWEEN THE 1932 KNOBLAUCH, RAISCH, HAUSEN AND KOCH STEAM TABLE VALUES AND THOSE OF TABLE XI

Differences are in parts per thousand and positive when the steam table values are the greater

°C	1 kg/cm.^{2}	10	50	100	200	250
200	−1.10	−0.11				
300	−0.80	−0.75	+0.37			
400	−0.58	+0.18	+2.06	+3.27	+3.55	+3.42
500	−0.32	+0.92	+4.55	+6.25	+6.00	+6.07
550	−0.194	+1.20	+5.60	+8.05	+8.20	+7.10

fact that much of the data in the present steam papers was available for use at the time of their compilation. The Callendar-Moss values are larger than the computed, for example along the 400° isotherm by from 0.2 to 0.3 parts per thousand.

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[50] The digits following the numbers are the indices of 10 forming the factors by which the numbers are to be multiplied. Thus the value of −B at 200° is 7.4531×10^{-2} or 0.074531.

In view of the expectation that the results of the extensive series of experimental determinations of enthalpy by our British, German and Czechoslovakian colleagues will be published in the near future, more extended comparisons with steam table values will not be presented here. It is of interest at this time to note that enthalpy values over the temperature range 0 to 550° and to pressures of 300 kg./cm.^{2} were adopted by the Third International Steam Tables Conference[61] held in the United States in September, 1934. The Table XI values are in accord with the conference values to the order of one per thousand or better over the range of temperature and to pressures including 250 kg./cm.^{2}

THE SPECIFIC HEAT CAPACITY OF SUPERHEATED STEAM

The heat capacity of steam for constant pressure may be very readily computed by means of an equation derived by differentiation from the enthalpy equation, 15A. The differentiation of the coefficients of the pressure was carried out directly for $\frac{\partial A}{\partial T}$ equal to $\tau(\beta - B_o)[0.20257 + 0.1886 \cdot 10^6\tau^2 + 0.014048 \cdot 10^{12}\tau^4]$ I. j. The derivatives of the coefficients B and C were obtained from a 10° interval table by using the Rutledge method already mentioned. In this instance three derivatives for each temperature were evaluated from the Rutledge coefficients and the average accepted as the true derivative desired. In the case of the D pressure coefficient its change with temperature is large and the differentiation operation was carried out on the logarithm of D. The Table XIV contains the coefficients of the C_p equation (I. j., kg./cm.^{2}) for each twenty degrees between 100° and 500° inclusive. The Table XV contains a few comparisons between the latest high pressure observed values of W. Koch[62] and those computed. An impression of the accord between all of the most recent specific heat measurements over the pressure range 30 kg.[63] to 200 kg. may be obtained from Fig. 5. It will be noted that the computed values for pressures of 120 kg. and lower pressures (+ points) lie systematically below the observed data to an increasing extent as the saturation line is approached. At 120 kg. there are two independent series of observations, the latest of which are smaller numerically than the earlier low pressure series. In the later series of measurements Dr. Koch modified his apparatus for the purpose of insuring the elimination of fog or liquid water particles in the steam. The possibility is not excluded that in the earlier measurements entrained water or fog was present which would be increasingly difficult to eliminate as observations were carried out nearer the saturation limit.

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[61] Mech. Eng., *57*, 701 (1935).

[62] W. Koch, Forschung auf dem Gebiete des Engenieurwesens, *3*, 1 (1932).

[63] Knoblauch and Koch, Zeit. Ver. Deutsch. Eng. *72*, 1733 (1928).

TABLE XIV

Pressure Coefficients of the Equation for the Constant Pressure Specific Heat Capacity of Steam

$$C_p = C_p^\circ + A^1p + B^1p^2 + C^1p^4 - D^1p^{13}$$

kg./cm.^{2}, Int. j.

t	A'	B'	C'	$-D'$
100	1.5954:−1	2.921:−2		negligible
120	1.1093:−1	1.446:−2	4.596:− 5	“
140	7.979:−2	7.612:−3	1.492:− 5	“
160	5.907:−2	4.221:−3	5.306:− 6	“
180	4.483:−2	2.447:−3	2.035:− 6	“
200	3.477:−2	1.474:−3	8.320:− 7	“
220	2.748:−2	9.183:−4	3.595:− 7	2.812:−21
240	2.208:−2	5.890:−4	1.628:− 7	1.330:−22
260	1.801:−2	3.877:−4	7.683:− 8	7.416:−24
280	1.488:−2	2.611:−4	3.756:− 8	4.744:−25
300	1.244:−2	1.794:−4	1.892:− 8	3.431:−26
320	1.051:−2	1.255:−4	9.787:− 9	2.765:−27
340	8.967:−3	8.928:−5	5.175:− 9	2.449:−28
360	7.717:−3	6.444:−5	2.787:− 9	2.348:−29
380	6.693:−3	4.713:−5	1.524:− 9	2.387:−30
400	5.848:−3	3.489:−5	8.423:−10	2.485:−31
420	5.143:−3	2.612:−5	4.692:−10	2.451:−32
440	4.550:−3	1.974:−5	2.622:−10	1.637:−33
460	4.049:−3	1.506:−5	1.463:−10	−1.563:−34
480	3.622:−3	1.159:−5	8.087:−11	−1.226:−34
500	3.255:−3	8.794:−6	4.390:−11	−4.900:−35

The digit following the numbers are the indices of 10 forming the factors by which the numbers are to be multiplied. Thus the value of B' at 100 is 2.921×10^{-2} or 0.02921.

On the other hand it must not be overlooked that in the computations we are compelled to deal with second derivatives of volume with respect to temperature. Thus, even if it is admitted that the primary p, v, T data are exact and the selected empirical equation used appears satisfactory, it does not necessarily follow that derivatives obtained by differentiation of the primitive equation will be exact. Of course the need for accurate derivatives was kept in view in working out the equation of state 9 and due care was exercised in the methods of obtaining the derivatives therefrom.

The importance of reliable specific heat measurements such as those of Knoblauch and Koch, and Koch is considerable for the measurements may be made the basis for a tabulation of thermodynamic properties as has been pointed out by Koch. The data are also a severe test of the precision of p-v-T data and especially of the formulation used to represent volume data. The order of agreement of our computed specific heats with the observations, while not entirely within the limits of precision of the latest Koch measurements, is nevertheless a satisfactory indication that the equation of state 9 possesses no inherent defects when used within the limits specified.

Heat Capacity of Superheated Steam

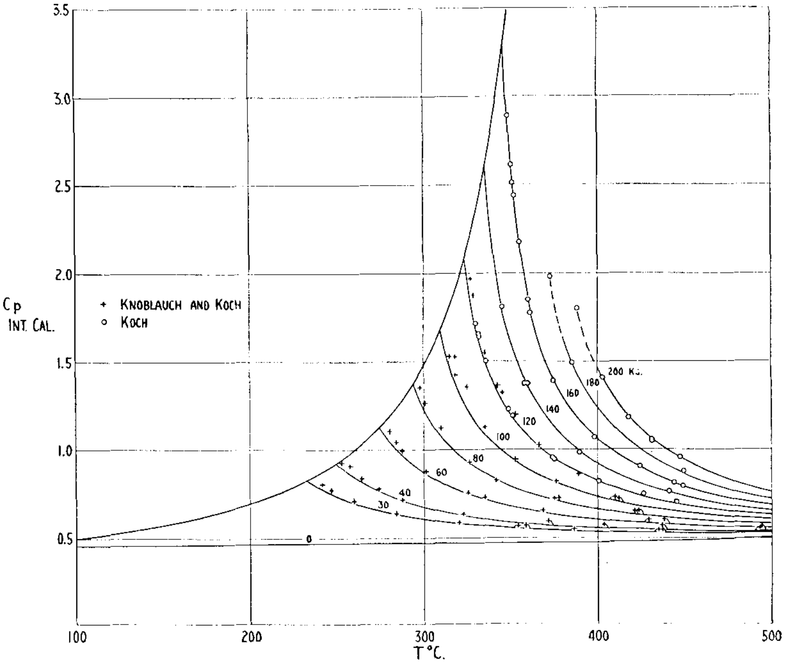

Figure 5

THE ENTROPY OF SATURATED AND SUPERHEATED STEAM

The general equation for the entropy is most conveniently derived from the differential equation $\left(\frac{\partial S}{\partial p}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_p$ in view of the p, v, T data available. The limits of pressure are to be zero and finite pressures; of temperature, the ice point, T_o and T. We proceed with the integration as follows, adding and subtracting $R \log p$:[64]

$$S_1 = f(T) - R \log p + \int_o^p \left(\frac{R}{p} - \left(\frac{\partial v}{\partial T}\right)\right) dp + S_{o1}^\circ \qquad (24)$$

The quantity in brackets is zero where $\left(\frac{\partial v}{\partial T}\right)_p$ is given by $\frac{R}{p}$ as for the case $pv = RT$. Using the equation of state 9 and noting that $f(T)$ is given by $\int_{T_o}^T C_p^\circ \, d \log T$, we obtain for the S_1 equation:

$$S_1 = \int_{T_o}^T C_{p1}^\circ \, d \log T - 1.06242 \log_{10} p - \int_o^p \left(\frac{\partial B}{\partial T}\right)_p dp + S_1^\circ \qquad (24A)$$

The first integral we will evaluate using equation 22, resulting in the following expression:

$$\int_{T_o}^T C_{p1}^\circ \, d \log T = 3.38937 \log_{10} T/T_o + 7.5566 \cdot 10^{-4} (T - T_o) + 47.8365 (\tau_o - \tau) \qquad (25)$$

The evaluation of the remaining integral is facilitated once a table of B_o, φ_1, φ_3 and φ_{12} values and the pressure coefficients (Table XII) of the enthalpy equation 15A is compiled. The integral to be evaluated may be expressed as follows, using equation 5:

$$\int_o^p \left(\frac{\partial B}{\partial T}\right)_p dp = \frac{\partial B_o}{\partial T} p + \frac{1}{2} \frac{\partial \varphi_1}{\partial T} p^2 + \frac{1}{4} \frac{\partial \varphi_3}{\partial T} p^4 - \frac{1}{13} \frac{\partial \varphi_{12}}{\partial T} p^{13} = Kp + Lp^2 + Mp^4 - Np^{13} \qquad (26)$$

The coefficients A, B, C and D are equal respectively (Eq. 15) to $\frac{\partial B_o \tau}{\partial \tau}, \frac{1}{2} \frac{\partial \varphi_1 \tau}{\partial \tau}$, etc., whence it follows that $\frac{\partial B_o}{\partial T} = K = \tau \left(B_o - \frac{\partial B_o \tau}{\partial \tau}\right)$

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[64] This device avoids an infinity which would otherwise appear in the integral.

TABLE XV

Computed Heat Capacities Compared with the Recent Measurements of W. Koch
Units Int. joules/g.

t	120 kg./cm.^{2}			140		160		180		200	
	I	II	Comp.	obs.	comp.	obs.	comp.	obs.	comp.	obs.	comp.
340	5.926	5.788	5.708	8.969	8.948						
360	4.507	4.466	4.479	5.658	5.624	7.789	7.791				
380	3.846	3.813	3.836	4.449	4.501	5.386	5.420	6.818	6.864		
400	3.465	3.432	3.427	3.834	3.877	4.373	4.441	5.110	5.168	6.127	6.164
420	3.223	3.189	3.152	3.469	3.474	3.821	3.862	4.273	4.332	4.859	4.905
440	3.059	3.022	2.960	3.231	3.200	3.482	3.481	3.788	3.810	4.168	4.195
460	2.942	2.900	2.822	3.063	3.007	3.256	3.218	3.478	3.459	3.741	3.735

The column marked I is from the data of the investigation published in 1928 as given in Table I of the 1932 Steam Tables of Knoblauch, Raisch, Hausen and Koch. The column marked II is taken from Table 2 of W. Koch's paper of 1932.

with similar relations for L, M, and N, due attention being paid to the fractions ½, ¼, and 1/13. Table XVI gives an abbreviated set of the coefficients valid for units kg. per cm.², int. joules per degree.

TABLE XVI

COEFFICIENTS OF PRESSURE FOR EQUATION 26

Int. j./deg.; kg.

t	K	L	M	$-N$
100	2.603−2	2.255−3	6.730− 6	
200	7.078−3	1.364−4	4.146− 8	8.944−22
300	2.965−3	1.765−5	9.790−10	4.670−28
400	1.570−3	3.556−6	4.016−11	3.018−33
500	9.601−4	9.182−7	1.222−12	1.258−36

The constant $S_1°$ is determined from a single value of S. That at 100° is conveniently taken from the work of Osborne, Stimson and Fioch at the National Bureau of Standards. The entropy of liquid water is given at 100° relative to 0° as 1.3059 joules per degree.[65] The entropy of evaporation at 100° from the same source is 6.04724 giving for the entropy of the saturated vapor at 100° (373.16) and 1.03323 kg./cm.² the value 7.3536 int. joules per degree. From Table XVI we find $\int_o^{1\text{ atm.}} \frac{\partial B}{\partial T} dp$ to be 0.0293. The value of $\int_{T_o}^{T} C_{p1}° \, d \log T$ is 0.5817, and $S_1°$ becomes 6.8158 joules per degree K. The entropy at 0° C ($p = 0.006226$ kg.) may now be computed and is found to be 9.1577 joules per degree K. This number when multiplied by 273.16 gives 2501.52 I. j., a number which should be equal numerically to the heat of evaporation at zero. The number obtained from the enthalpy equation is 2501.86, a sufficiently satisfactory correspondence.

Table XVII contains a few values of the entropy for a range of temperatures and pressures computed from the equation 23A, using the equation 24, the coefficients of Table XVI and the constant 6.8163. The values from the Knoblauch, Raisch, Hausen and Koch steam tables have been entered in the table for comparison. Other values might also be entered for comparison but it is anticipated that in the near future a considerable body of new data will be reported and for this reason it seems best to postpone detailed intercomparison.

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[65] This value as originally given is computed assuming T^0 to be 273.10 instead of 273.16. The number is therefore larger by about two units in the last place. The figure used has been communicated privately by Doctor Osborne.

The numerical values for other thermodynamic functions would be of interest, particularly the energy and the function $F = H - TS$. The latter can of course be easily computed from the values of H and S given in the present paper. In the case of the energy however it would be advantageous to represent the p-v-T data with pressure as the explicit variable thereby facilitating the computation of the term $\left(\frac{\partial p\tau}{\partial\tau}\right)_v$ of the energy equation:

$$U = \int_{T_0}^{T} C_v\,dT - \int_{o}^{p}\left(\frac{\partial p\tau}{\partial\tau}\right)_v dv + U^\circ \qquad (26)$$

In a later paper the equation of state in the form $p = f(vT)$ will be given and the energy of steam computed from an equation of the above form. Values of the energy can of course also be computed from the relation $H - pv = U$, using the data of the present paper.

TABLE XVII

ENTROPY OF STEAM

Calories per degree Kelvin*

t	Kg./cm.² 1	10	50	100	200	250
100	[1]1.7603					
	[2]1.7604					
200	[1]1.8713	1.6005				
	[2]1.8735	1.6011				
300	[1]1.9627	1.7018	1.4859			
	[2]1.9642	1.7036	1.4863			
400	[1]2.0404	1.7841	1.5920	1.4910	1.3378	
	[2]2.0421	1.7848	1.5903	1.4879	1.3335	
500	[1]2.1100	1.8555	1.6730	1.5855	1.4790	1.4362
	[2]2.1112	1.8553	1.6682	1.5789	1.4723	1.4307

THE JOULE-THOMSON COEFFICIENTS

A comprehensive investigation of the Joule-Thomson effect in steam was made by Davis and Kleinschmidt, comprising part of the 1921 A. S. M. E. program of steam research. Data were reported as early as 1923.[66] The work was carried out for temperatures 125 to 400 inclusive, and for pressures extending to 40 kg./cm.^{2} The older results of similar measurements have been already critically discussed

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* Units are Int. joules/g. $\times \frac{1}{4.18605}$ or Int. steam calories per degree Kelvin.

[1] From the tables of Knoblauch, Raisch, Hausen and Koch.

[2] Computed from the entropy equation.

TABLE XVIII

DAVIS AND KLEINSCHMIDT JOULE-THOMSON COEFFICIENTS COMPARED WITH COMPUTED VALUES

Units °C per Kg./cm.^{2}

$p \frac{\text{kg.}}{\text{cm.}^2}$	*D* and *K*	Comp.
	$t = 125°$	
1.125	4.801	4.908
	$t = 145°$	
1.405	3.730	3.928
2.81	3.998	4.009
	$t = 166°$	
1.60	2.973	3.180
1.76	3.092	3.182
2.85	3.209	3.228
5.62	3.264	3.270
	$t = 196°$	
1.60	2.368	2.405
3.52	2.409	2.451
7.04	2.557	2.500
7.04	2.474	
7.60	2.522	2.505
10.55	2.570	2.500
10.55	2.490	
	$t = 225°$	
1.60	1.882	1.910
3.16	1.995	1.930
7.04	1.978	1.970
10.55	1.948	1.985
14.77	1.987	1.990
20.25	1.953	1.970
20.25	2.001	
	$t = 260°$	
1.60	1.485	1.495
3.16	1.536	1.506
10.55	1.549	1.539
14.77	1.548	1.548
15.11	1.577	1.549
20.00	1.551	1.550
25.30	1.545	1.543
32.40	1.533	1.526
39.60	1.511	1.499
	$t = 300°$	
1.70	1.163	1.168
3.16	1.193	1.174
8.44	1.192	1.188
14.00	1.207	1.199
15.00	1.197	1.199
20.25	1.201	1.202
32.70	1.187	1.199
	$t = 347°$	
1.60	0.932	0.905
7.38	0.929	0.918
15.00	0.928	0.922
35.00	0.919	0.926

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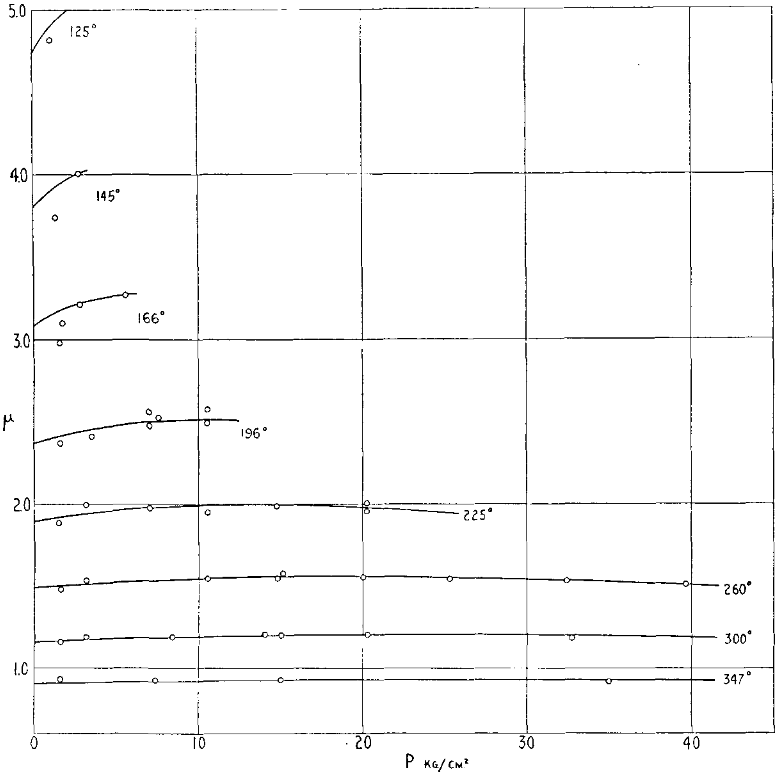
[66] R. V. Kleinschmidt, Mech. Eng. *45*, 165 (1923). H. N. Davis, Mech. Eng. *45*, 85 (1924); *47*, 107 (1925). J. H. Keenan, Mech. Eng. *48*, 144 (1926). R. V. Kleinschmidt, Mech. Eng. *48*, 155 (1926). H. N. Davis and J. H. Keenan, No. 455, World Eng. Conference Reports, Tokyo, 1929.

by H. N. Davis.[67] The first attempt to compute Joule-Thomson coefficients from the present volume data was published recently[68] using for $C_p{}^\circ$ a relation deduced from a reduction of the recent enthalpy, specific heat and Joule-Thomson data referred to above. In the later paper a modification of the equation of state proposed to


JOULE-THOMSON EFFECT VALUES

— = COMPUTED; O = OBSERVED

FIGURE 6

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[67] H. N. Davis, Proc. Am. Acad. Arts and Sci. *44*, (1909). See also Proc. Am. Soc. Mech. Eng. *30*, 1419 (1908).

[68] Keyes, Smith and Gerry, Mech. Eng. *57*, 113 (1934); also Mech. Eng. *59*, 164 (1935).

represent the present volume data to 10 cc. per gram was reported and a diagram given showing the agreement of new computations with the Davis and Kleinschmidt results. In these computations Gordon's $C_p°$ values were used as given by Eq. 22.

The coefficients may readily be computed from the equation for enthalpy, 14, by differentiation resulting in the following equation:

$$\mu = \left(\frac{dT}{dp}\right)_H = -\frac{\left(\dfrac{\partial B\tau}{\partial\tau}\right)_p}{C_p° + \partial/\partial T\left(\displaystyle\int \frac{\partial B\tau}{\partial\tau}\,dp\right)}$$

Tables XII and XIV give the data from which the Joule-Thomson numbers may be computed for the temperatures listed. Table XVIII gives for comparison the observed data under columns D and K and the computed Joule-Thomson values under the columns labelled "comp." The accord of the computations with the observations appears quite satisfactory but from figure 6 it is clear that the calculation does not reproduce the low pressure point at 125, 145, and the two low pressure points of the 166 isotherm. Aside from these defects, the accord with the observations appears to be everything that could be expected. The effect provides exceptionally good data for testing the equation of state, and the discrepancies noted may be an indication of a failure of the equation to give accurate results below 190°. Further information on this point will be forthcoming when the results of additional direct measurements of $\left(\frac{\partial H}{\partial p}\right)_T$ and μ are available using the new calorimeter referred to earlier (Part 1, reference 38). The new measurements will also supply information on the heat capacity of steam since this quantity is equal to the ratio of the isothermal increase of H with pressure to the Joule-Thomson effect.

NOTE: A most important paper by Max Jacob and W. Fritz appeared in Physikalische Zeitschrift, *36*, 651, 1935, containing a full report of their measurements on the physical properties of steam. This work appeared after the present paper had been sent in for publication. A comparison of the Jacob and Fritz work with the present results will be made in a later paper on the properties of steam.

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Vol. 70, No. 9—February, 1936

PHILIPPINE PHORIDAE FROM THE MOUNT APO REGION IN MINDANAO

By Charles T. Brues

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PHILIPPINE PHORIDAE FROM THE MOUNT APO REGION IN MINDANAO

By Charles T. Brues

PHILIPPINE PHORIDAE FROM THE MOUNT APO REGION IN MINDANAO

BY CHARLES T. BRUES

Biological Laboratories, Harvard University

Received 12 December, 1935 Presented 11 December, 1935

The material on which the present paper is based was collected by Mr. C. F. Clagg who spent a number of months during 1930–31 in the Mount Apo region in southern Mindanao. Among the many Diptera which he obtained there is an extensive series of Phoridæ, which has been acquired, together with much material in other families, by the Museum of Comparative Zoölogy.

Mr. Clagg made his collections at various localities in the province of Davao in southeastern Mindanao. Most of the species described in the present paper were collected on Mt. Apo, an active volcano. This mountain is the highest peak in the Philippines rising to an altitude of 9610 feet (2929 meters) according to the latest surveys.

Most of the collecting on Mt. Apo was done on the east and southeast slopes beginning the last part of August and continuing to the end of November 1930, at altitudes from 5,000 to 8,000 feet. A few specimens were taken at lower altitudes when trips down to the lowlands were necessary to replenish provisions.

As no members of the wild tribe of Bagobos who control the eastern slopes of the mountain live above 4,000 feet altitude, it was necessary to cut trails through the dense forest before any collecting could be done. Heavy rain every day for the first 28 days, above 4,000 feet, also made collecting of delicate specimens a problem. This superabundance of moisture and the dense vegetation may account to a certain extent, for the great richness of the fauna.

Mr. Clagg also collected some Phoridæ at Lawa and Calian, two river valleys on the west coast of Davao Gulf, and in the Lalun Mts. at the headwaters of these two rivers, at an altitude of 5500 feet. Two different trips were made to the Lalun Mts., one during the first week of July 1930 and the second between Christmas 1930 and January 5, 1931. During the last week in January 1931, he ascended Mt. Mayo back of the town of Mati in the eastern peninsula of Davao and collected near the summit, between 4,000 and 5,000 feet.

The Phoridæ of the Philippines have hitherto remained practically unknown, so that it is not surprising to find that practically all those secured by Mr. Clagg prove to be undescribed. Eight genera are represented in the present collection, but most of the species belong to the large and widespread genus Megaselia. None of the genera are described as new, although one remarkably modified species which I have tentatively referred to Johowia, a monotypical South American genus, may possibly prove to deserve generic rank. Some of the species are closely similar to Palæarctic ones. Of several generally tropicopolitan species of Megaselia, no specimens appear in Mr. Clagg's collections, but this is to be expected since the material came from a region as yet totally unspoiled by advancing civilization and commercial intercourse.

The figures which accompany the descriptions are from drawings made by Mrs. Martin O'Connor to whom I am indebted also for aid in preparing the manuscript for the printers.

The types of the new species are in the collections of the Museum of Comparative Zoology at Harvard University.

PARASPINIPHORA Malloch

Paraspiniphora apicalis sp. nov. (Fig. 1)

♂. Length 2.4 mm. Black, pleuræ, antennæ and posterior legs brownish; front legs and palpi yellowish; abdominal tergites narrowly pale margined; wings slightly infuscated, the heavy veins black. Front slightly wider than high, its bristles strong; four postantennal bristles; the lower pair very close together; upper pair well separated; lower transverse row of four bristles curved upward medially, the inner bristles nearly as far from one another as from the eye margin; upper row strongly convex above also. Antennæ large, as high as the eye width; usually dark brown, sometimes more honey-yellow. Palpi of moderate size, with very stout, but short bristles, considerably lighter in color than the antennæ; postocular cilia enlarged below; one long bristle on the cheek. Mesonotum shining, with sparse minute hairs and two pairs of dorsocentral bristles, the posterior ones farther apart and very close to the hind edge; scutellum with four strong bristles. Front legs yellow, their tibiæ with a strong dorsal bristle just before the middle; middle legs darker, more brownish, with a pair of bristles just before the basal third and a stronger anterior one at the apical third; posterior tibia with four bristles, a posterior dorsal one at the basal third, and another just before apex, a dorsal one just beyond the middle and an anterior ventral one at the middle, the last weaker than the others. Abdomen dull black, more shining at tip, tergites one to six narrowly margined behind with yellowish white; second and sixth elongated, each nearly twice as long as the third, the second with a tuft of rather short bristles at each side. Hypopygium black, with a short pale lamella; curved forward under the tip of the abdomen as an arcuate, strongly bent process that bears conspicuous backwardly directed small bristles. Wings slightly but distinctly tinged with brown, the heavy veins black and the light ones dark; first section of costa twice as long as the second and third together, the costa ending a little beyond the middle of the wing, very thin at the base and distinctly arched beyond the tip of the first vein; its edge with very short and delicate cilia; second vein very thin, almost parallel with the tip of the third so that the last section of the costa is very short; third vein with a single bristle at the base; fourth vein straight except at base; fifth parallel with the fourth beyond the middle; sixth widely divergent from the fifth; seventh gently curved. Halteres pale.

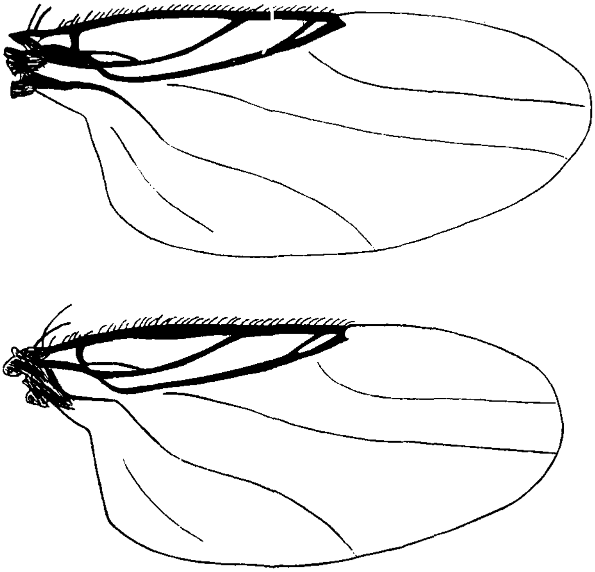

FIGURE 1. *Paraspiniphora apicalis* sp. nov. a, wing of male; b, wing of female.

♀. Length 2.8–3.2 mm. The mesonotum is piceous or fuscous and the antennæ orange yellow, no darker than the palpi. The abdomen lacks the pale margins almost entirely, except on the first segment. The apical portion, including apex of the fourth and all of the following segments, orange or yellow. Antennæ not enlarged; seventh abdominal tergite deeply incised medially. Tarsal claws, especially on the front legs, greatly enlarged, empodium ribbon-like. Costa much thickened between the anterior cross-vein and the tip of the first vein, slightly so thence to its tip.

Type male and eight other males and thirteen females from Baco, Mindoro, Philippines, October 30. One other female from Calapan, Mindoro.

This is the first species of the genus to be described from the Philippines. It is readily recognizable by the striking coloration of the abdomen in the female as well as by the noticeably swollen costa in that sex. The male is quite similar to *P. bergenstammi*, differing in coloration and in the form of the hypopygium.

DIPLONEURA Lioy

Diploneura evanescens sp. nov.

♀. Length 4.2 mm. Black; the antennæ piceous; palpi pale yellow; proboscis and front legs fuscous, the posterior legs almost black; wings hyaline, the costal margin infuscated beyond the costal vein; heavy and light veins piceous; halteres black. Front about as wide as high, the frontal bristles long; two postantennal bristles very close together; bristles of lower transverse row in a line that curves downward strongly at the middle, the median ones twice as far from one another as from the adjacent lateral one which is widely separated from the eye; middle row forming a straight transverse line, its bristles equidistant with the lateral ones near to the eye; upper edge of front forming a raised carina which curves slightly downwards at the sides so that the lateral bristles of the ocellar row arise above it; surface of front subshining. Post-ocular cilia strong; two moderate bristles on each cheek. Antennæ small, piceous when seen from above, the third joint honey-yellow below; palpi rather broad in profile, with about six moderate sized apical bristles. Proboscis heavily chitinized, about as long as the head height. Mesonotum quite distinctly shining although clothed with rather dense microscopic hairs. One pair of widely separated dorsocentral bristles in line with the lateral edges of the scutellum; four very long scutellar bristles forming an approximate pair at each side of the scutellum. Propleura with two appressed bristles below the spiracle and a pair at the lower edge; mesopleura bare. Abdomen with four chitinized tergites, without conspicuous hairs except for scattered bristly hairs on the apical part of the sixth segment and some smaller ones on the seventh; ovipositor short, pointed, yellow, with sparse delicate bristly hairs toward apex, apparently somewhat chitinized. Legs slender; front tibiæ with a long dorsal bristle at the middle and a series of five or six minute ones distributed along the apical third; middle tibiæ with a pair of dorsal bristles at the basal fourth and a series of about ten oblique rows of minute comb-like setæ dorsally on the apical two-fifths, also with a pair of dorsal hair-seams that separate and become obsolete apically; hind tibiæ with two complete dorsal hair-seams and two bristles external to the outer seam, one at the basal third and the other at the apical third, also with a few transverse comb-like rows of setæ near apex internally. Costa extending well beyond the middle of the wing, its bristles minute and closely placed; first section of costa one-third longer than the second; third section not developed as the second and third veins are practically fused, leaving only a faint trace of the usual fork; first vein lying very close to the third which bears a small bristle at its base; fourth vein moderately curved and distinctly recurved at apex; fifth to seventh veins nearly straight.

Type from the Mainit River, 5,000 feet altitude, Mt. Apo, Mindanao, Philippines, collected on September 15, 1930 (C. F. Clagg).

This is a member of the typical subgenus Diploneura, quite similar to *D. dohrniphoridea* Assmuth from the Bismarck Archipelago in the enlarged, chitinized proboscis and unforked third vein. It differs in the row of small bristles on the front tibia, arrangement of frontal bristles and the four subequal scutellar bristles, as well as the presence of only four dorsal abdominal plates.

Diploneura (*Dohrniphora*) **cornuta** Bigot

One male of this tropicopolitan form from Samar Island.

STICHILLUS Enderlein

Stichillus adæqualis Schmitz

Naturh. Maandblad, vol. 16, p. 63 (1927).
Schmitz, Revision der Phoriden, p. 114 (1929).

There are three males and three females of this species. They were taken by Mr. Clagg along the Galog River at 5,000 feet, November 3d and 6th; along the Mainit River (6,000 ft.), November; on the Kidapawan Trail, at 7,000–8,000 feet, Cotobato Province September 30th; and at Lawa, Davao Province. They agree closely with Schmitz's description except that the lower lateral bristles of the front are closer to the postantennals than in his type material, but there is some variation in this respect in the specimens collected by Mr. Clagg. The female is similar to the male except for the smaller, rounded antennæ which are of the form characteristic of the females of this genus. The types came from Heigthpol.

Some of the present specimens are larger than the type (3 mm.) and the others much smaller (1.7 mm.), but I can detect no structural differences.

CONICERA Meigen

Conicera philippinensis sp. nov.

♂. Length 1.4 mm. Brownish-black, the pleuræ decidedly brown, especially below; legs yellowish brown, the four posterior femora and tibiæ piceous, except at tips; antennæ and palpi black; wings noticeably tinged with brown, the costa nearly black, but the other thick veins fuscous. Postantennal bristles very much smaller than the præocellar ones, rather close together; antial bristles apparently not developed; præocellar row of four strong equidistant bristles; postocellar bristles of about the same size as the præocellars and directly above them. Between the bristles the front bears scattered small bristly hairs, its surface opaque black. Antennæ of the usual pointed form, their tips reaching to the level of the lower ocellus. Palpi with short, equal bristles below on their apical half; cheeks each with a single strong bristle and two much smaller ones between it and the palpus near the lower eye-margin. Mesonotum slightly shining on the surface, clothed with small bristly hairs that form more or less distinct longitudinal lines; one pair of short dorsocentral bristles; scutellum semicircular, with two marginal bristles. Propleuræ with scattered hair-like bristles and a series of larger ones along the posterior margin; mesopleuræ entirely bare. Upper surface of abdomen very dull, the second and sixth tergites elongated, each nearly twice as long as one of the intervening ones. Base of hypopygium light brown. Anterior tibia with a dorsal bristle of moderate size at the basal third and a series of minute but very distinct bristles extending from this to the tip; anterior tarsus one-third longer than the tibia; middle tibia with a pair of dorsal bristles at the basal fourth, the antero-dorsal one somewhat shorter and slightly nearer the base of the tibia, also a postero-dorsal bristle at the apical fourth; hind tibia with a pair of almost equal dorsal bristles at the basal fourth and a strong antero-dorsal one just beyond the middle; beyond this bristle is a flattened pale-colored area entirely without hairs, extending to the tip of the tibia. Costa about two-fifths the wing-length, with very short cilia; first and third veins of the usual form, the first section of the costa about twice as long as the second (15: 7); fourth vein gently and evenly curved;

fifth nearly straight; sixth as strong as the fourth and fifth; seventh only faintly indicated, entirely obsolete at the base. Halteres black.

This is the first species of the genus to be discovered in the Philippines. It differs from *C. procericornis* Schmitz from the Bismarck Archipelago by the shorter first section of the costa and much longer front tarsi. From the Formosan, *C. breviciliata* Schmitz, it differs in having the first section of the costa much longer and from *C. formosensis* Brues by the longer first section of the costa and brownish wings with lighter colored heavy veins. Whether the flattened, hairless area on the hind tibia is distinctive, I do not know. It is not present in *C. dauci* Meigen and is not mentioned in descriptions of other species of the genus. In *C. formosensis* Brues there is a slight indication of such a modification, but the area is clothed with minute hairs like the remainder of the tibia.

MEGASELIA Rondani

This genus is quite cosmopolitan and in practically every region is represented by many more species than any of the other genera comprising the family. That Megaselia is likewise the dominant genus of Phoridæ in the Philippine Islands is shown conclusively by the present collection which contains no less than 68 species. Moreover this collection, although extensive, came from a very limited area in the region of Mt. Apo in Mindanao and must presumably represent only a very small part of the existing Philippine fauna. Unfortunately this fauna has hitherto remained practically unknown. Up to the present time some 579 species of Megaselia have been described, of which 360 occur in Europe, 93 in North American and 108 in the Neotropical region, so that although the genus is already of very great extent, the forms here included from this small area in the Philippines form a very considerable and unexpectedly large addition. It seems, indeed, that speciation has been far more active in this region than in any other so far examined. Certainly no collector could have obtained a comparable number of species in so limited a time in such a circumscribed area in Europe or America and one may reasonably expect future collections of Philippine Diptera to contain a great wealth of species of Megaselia.

Megaselia *s. str.* and Aphiochæta are here regarded as subgenera, the proportion of species in each being about equal as is the case in Europe and most other parts of the world. The characters used in the key and descriptions are those in general use, but it may be stated specifically that in describing the wing venation, the length of the costa is measured from the somewhat larger bristle at the base of the wing. The measurements of the costal sections are from the humeral cross-vein to the inner angle where the first vein enters, thence to the inner angle where the second vein enters, and thence to the tip of the costa, these three lines defining the length of the three sections of the costa. As has been done by Schmitz, the lowest pair of reclinate bristles on the front are termed antials (Antialen) and the proclinate bristles on the front, postantennals.

Key to the Philippine Species of Megaselia here Described

Mesopleura above, near the base of the wing, bearing a patch of hairs or minute bristles, sometimes supplemented by one or two large, backwardly directed bristles. (Subgenus **Aphiochæta** Brues) . . . 1

Mesopleura entirely bare, without such hairs or bristles. (Subgenus **Megaselia** *s. str.*) 36

1. Mesopleura above with one very large bristle (very rarely two), in addition to a patch of short hairs or very minute bristles. . 2

Mesopleura above with a patch of minute bristles, two or several of which may be slightly larger than the others 22

2. Hind tibia with two rows of setulæ dorsally, one inside and one outside the hair-seam 3

Hind tibia with a single dorsal row of setulæ, placed inside the hair-seam, or with the setulæ obsolete 8

3. Thorax and legs yellow; tibial setulæ weaker, not as long as the width of the tibia; third section of costa less than half as long as the second 4

Thorax black or piceous; hind legs mainly black 5

4. Second section of costa longer than the first and fully four times as long as the third; tip of abdomen in ♀ beset with many short bristles; antennæ and palpi dark; large species . . . . *M. scopifera* sp. nov.

Second section of costa considerably shorter than the first and not more than three times as long as the third; tip of abdomen in ♀ not bristly; antennæ and palpi pale; smaller species . . . . . *M. labialis* sp. nov.

5. First section of costa about as long as or longer than the second and third sections together 6

First section of costa much shorter than the second and third together; outer series of setulæ on hind tibia moderately strong; third section of costa three-fourths as long as the second . . . . *M. baroringensis* sp. nov.

6. Outer series of setulæ on hind tibia strongly developed, its bristles almost as long as those of the inner series 7

Outer series of setulæ on hind tibia weakly developed, its bristles very much shorter than those of the inner series; upper postantennal bristles separated by one-third the width of the front *M. nocturnalis* sp. nov.

7. Knob of halteres white; third section of costa considerably more than half as long as the second; upper postantennal bristles separated by less than half the width of the front; fourth vein slightly bent at base. . . . .*M. claggi* sp. nov.

Knob of halteres brown; third section of costa but little more than half as long as the second; upper postantennal bristles separated by half the width of the front; fourth vein sharply bent at base. . . . .*M. trisecta* sp. nov.

8. Front tarsi slender, not enlarged (if first joint is slightly enlarged see *M. lalunensis* and *M. perspinosa*, couplets 15 and 20). . .10

Front metatarsi strongly enlarged, other joints also distinctly widened. 9

9. Costa extending to the middle of the wing. 35

Costa much less than half the length of the wing, the fourth vein very weakly curved; a very small species. . *M. turbulenta* sp. nov.

10. Costa of female strongly thickened, especially toward the middle, its cilia very short; head and thorax yellow; abdomen black, with yellow spots at sides of second tergite. . . *M. costipennis* sp. nov.

Costa not swollen. 11

11. Black, the abdomen beyond the second segment bright orange-yellow; one or two of the mesopleural bristles slightly longer than the others (see couplet 31).

Black or brownish yellow; abdomen not thus colored. 12

12. Two scutellar bristles. 13

More than two scutellar bristles. 20

13. Knob of halteres black or brown, not lighter than the body . . .14

Knob of halteres white or pale yellow. 16

14. Female with a pointed, upcurved ovipositor; sixth abdominal segment bearing a group of long, stiff bristles on each side at apex; only two proclinate frontal bristles. . *M. cultrata* sp. nov.

Female without specialized ovipositor or such bristles at apex of abdomen; four proclinate frontal bristles. 15

15. Body and legs black or dark brown; antial bristles close to the eye margin; upper postantennal bristles unusually far apart. . . . . . . *M. lalunensis* sp. nov.

Thorax and legs yellow; antial bristles far removed from the eye margin; upper postantennal bristles in the usual position. . . . . *M. galogensis* sp. nov.

16. Two very long mesopleural bristles in addition to the hairs; third vein simple, not forked. . . . . *Plastophora dubitata* sp. nov.
Only one large mesopleural bristle; third vein forked as usual. . 17
17. Front much higher than wide; costal cilia short. 18
Front quadrate. 19
18. Apex of abdomen (♀) bearing a pair of flat plates, each fringed apically with stout bristles. . . . . *M. alata* sp. nov.
Apex of abdomen (♀) without such fringed plates. . . . . *M. mainitensis* sp. nov.
19. Costal cilia moderately long; first costal section as long as the second. . . . . *M. sibulanensis* sp. nov.
Costal cilia extremely short; first section of costa much longer than the second and third together; third two-thirds as long as the first; hind tibia with a very weak series of setulæ outside the seam (see couplet 6). . . . . *M. nocturnalis* sp. nov.
20. Six scutellar bristles, the middle one on each side much longer than the others; four large proclinate bristles. . . . . *M. perspinosa* sp. nov.
Four large, subequal scutellar bristles; lower proclinate bristles minute. 21
21. First section of costa longer than the second and third together. . *M. quadrispinosa* sp. nov.
First section of costa shorter than the second and third together. . *M. bakeri* sp. nov.
22. Hind tibiæ with two rows of strong setulæ, one inside and one outside the dorsal hair-seam, the outer one sometimes weak, especially in the male. 23
Hind tibiæ with only one row of setulæ, inside the seam; these sometimes weak or very weak. 29
23. Front metatarsus greatly swollen, or at least moderately thickened (♂), sometimes almost as large as the tibia. 24
Front metatarsus not noticeably enlarged. 25
24. Costal bristles very short; front metatarsus greatly swollen (♂); upper row of frontal bristles set high, the median pair much nearer to the level of the median ocellus than to that of the upper proclinate bristles; two or three bristles at apex of mesopleura noticeably longer than the others. *M. pectinata* sp. nov.
Costal bristles moderately long; front metatarsus moderately swollen; upper row of frontal bristles set lower, the median pair midway between the level of the ocellus and the upper proclinate bristles; mesopleural bristles all minute and approximately equal. . . . . *M. pilifera* sp. nov.

25. Costal bristles long or of moderate length 26

Costal bristles very short; fourth vein weakly curved or practically straight; slender species, the hind tibiæ slender, with the cilia widely spaced . . . . *M. humeralis* sp. nov.

26. Wings strongly infuscated; inner row of bristles on hind tibia very long, the outer row much weaker; legs very dark 27

Wings hyaline 28

27. Halteres dark; two strong bristles and two bristly hairs on scutellum; costal bristles moderate . . . . . . *M. tinctipennis* sp. nov.

Halteres white; four large, equally strong scutellar bristles; costal bristles long . . . . *M. umbrosa* sp. nov.

28. First section of the costa shorter than the second; smaller species, length 1.2 mm. . . . . *M. curtipes* sp. nov.

First section of the costa longer than the second; larger species, length over 2 mm. *M. debilitata* sp. nov.

29. Abdomen black basally, yellow beyond the second or third segment 30

Not thus colored 32

30. Postantennal bristles widely separated, occupying one-third the width of the front 31

Postantennal bristles close together, occupying only about one-fourth the width of the front . . . . *M. conspicua* sp. nov.

31. Fourth to sixth abdominal segments bright orange yellow; wing venation normal . . . . *M. fulvicauda* sp. nov.

Third and following segments ochre yellow, costa greatly swollen and distorted . . . . *M. pallidicauda* sp. nov.

32. Costal cilia long, approximately as long as the distance between the costa and the third vein at its middle; costa at least half the wing length 33

Costal cilia much shorter; front metatarsus enlarged in the female; costa less than half the wing length . . . . *M. brevineura* sp. nov.

33. First section of costa shorter than the second; costa extending well beyond the middle of the wing . . . . *M. aristata* sp. nov.

First section of costa as long as or longer than the second; costa extending about to the middle of the wing 34

34. First section of the costa twice as long as the second; brownish species . . . . *M. textilis* sp. nov.

First section of costa much less than twice as long as the second; blackish species . . . . *M. apoënsis* sp. nov.

35. Costal cilia short; antennæ of ordinary size . *M. inflatipes* sp. nov.

Costal cilia of medium length; costa reaching to middle of wing, its third section one-third as long as the second; antennæ of male distinctly enlarged.............*M. antennalis* sp. nov.

36. Hind tibiæ with two rows of small bristles, one inside and one outside the dorsal hair-seam..........................37

Hind tibiæ with only one row of small bristles, inside the seam.42

37. Four large, equally strong postantennal bristles, the upper pair widely separated..................................38

Two strong and usually also two very weak postantennal bristles..40

38. Scutellum with four large, equal bristles...................39

Scutellum with six bristles, the median pair rather small, the intermediate pair large and strong, and the lateral pair weakest.... *M. repetenda* sp. nov.

39. Abdomen with transverse segmental bands of pale yellow; knob of halteres pale; upper postantennal bristles separated by fully one-half the width of the front........*M. calianensis* sp. nov.

Abdomen entirely black; knob of halteres dark; upper postantennal bristles separated by less than half the width of the front...............................*M. equivocata* sp. nov.

40. Front yellow, considerably wider than high; antial bristle on each side far from the lowest lateral bristle, midway between the median line and the eye margin; first section of costa shorter than the second....................*M. bulbosa* sp. nov.

Front black, quadrate; antial bristle on each side lying close to the lowest lateral bristle; first section of costa longer than the second...41

41. Body, front and four posterior legs black..*M. dimidiata* sp. nov.

Body and legs brownish yellow; front and abdominal spots black............................*M. quadrata* sp. nov.

42. Scutellum with four bristles of equal or nearly equal size; if lateral bristles are conspicuously smaller, there are only two strong postantennal bristles...................................43

Scutellum with only two bristles and two very much smaller hairs...48

43. Second section of costa as long as or longer than the first......44

Second section of costa much shorter than the first...........46

44. Abdomen black; wings not spotted.........................45

Abdomen pale yellow; wing with a dark spot between the second and third veins...................*M. maculipennis* sp. nov.

45. Front and pleuræ yellow; front quadrate..*M. brevisecta* sp. nov.

Front and pleuræ black; front wider than high................ *M. linoënsis* sp. nov.

46. Lower postantennal bristles much reduced in size or absent...47

Upper and lower postantennal bristles of equal size; second and third veins very slightly divergent; antennæ of male moderately enlarged, yellow; hypopygium with the lower corners produced and bearing a tuft of slender stiff bristles.......... *M. setifrons* sp. nov.

47. Tip of abdomen of female prolonged, forming an ovipositor; head and thorax yellowish brown; antennæ enlarged, especially in the male..........................*M. tubulata* sp. nov.

Abdomen of the usual form; body black....*M. montana* sp. nov.

48. Second vein present, the third vein forked near apex as usual..49

Second vein entirely absent, the third vein not forked........54

49. Costa distinctly thickened near the middle..................50

Costa normal, not at all thickened or enlarged...............55

50. Costa greatly swollen near middle, normal on basal and apical thirds..52

Costa moderately but distinctly thickened, about twice the usual width near the middle; third vein straight as usual (♀)....51

51. Body black, wings distinctly infuscated, veins piceous; costal cilia long; first section of costa longest..*M. translocata* sp. nov.

Thorax entirely yellow; wings faintly yellowish brown; veins brown; costal cilia short; second section of costa longest...... *M. mediata* sp. nov.

52. Apex of abdomen in female with a pair of long upturned processes, one at each side; costa and third vein straight as usual.....53

Apex of abdomen in female simple, without such lateral, upcurved processes; costa and third vein strongly arcuate.............. *M. mutata* sp. nov.

53. Apical processes of abdomen long, thin, evenly curved and pointed, shaped like tarsal claws; the seventh tergite which lies just in front of them rhomboidal, truncate at apex................. *M. bihamulata* sp. nov.

Apical processes irregularly angulate, thicker; the seventh tergite triangular with a median ridge that is produced posteriorly into a downwardly curved spine........*M. appendiculata* sp. nov.

54. Costa swollen; third vein straight, lying so very close to the costa that the two are practically contiguous..*M. directa* sp. nov.

Costa normal, not swollen; third vein not unusually approximated to the costa.......................*M. incompleta* sp. nov.

55. Halteres pale colored or white, usually much lighter than the thorax...56

Halteres dark, usually much darker than the thorax.........58

56. Front, mesonotum and abdomen strongly shining, black; hind tibiæ constricted at base, with the hair-seam deflected before the middle, beyond which is a broad, flat groove bearing the tibial setulæ........................*M. politifrons* sp. nov.

Front, mesonotum and abdomen dull or subshining as usual; hind tibiæ not constricted at base........................57

57. Front and mesonotum yellow, costal cilia short. *M. bisecta* sp. nov.

Front and mesonotum black, costal cilia long. *M. unisetosa* sp. nov.

58. Body almost entirely pale yellow, except for the dark brown fifth tergite and last abdominal segment which is black and prolonged into a stout rod-like ovipositor. . *M. vapidicornis* sp. nov.

Body, or at least the abdomen, in great part black...........59

59. Costal cilia long.......................................60

Costal cilia short and weak...............................63

60. Thorax yellow or brownish yellow.........................61

Thorax black or piceous; front highly polished; front tarsi strongly enlarged; very small species............*M. clavipedella* sp. nov.

61. Four equal or nearly equal postantennal bristles.............62

Two strong and two very much weaker postantennal bristles.... *M. equisecta* sp. nov.

62. Upper pair of postantennal bristles much nearer to one another than to the eye-margin; front and antennæ black; abdomen shining above......................*M. barbata* sp. nov.

Upper pair of postantennal bristles very far apart, much nearer to the eye-margin than to one another; front and antennæ yellow; abdomen not shining.................*M. digressa* sp. nov.

63. First section of costa longer than the second................64

First section of costa no longer than the second, usually distinctly shorter..66

64. Lower pair of postantennal bristles as large as the upper pair; front much wider than high..........*M. extensifrons* sp. nov.

Lower postantennal bristles very much smaller than the upper ones; front quadrate.................................65

65. Front, legs and thorax yellow; hind tibiæ with only one series of bristles, inside the seam..............*M. apposita* sp. nov.

Front, thorax and four posterior legs black; hind tibiæ with a series of extremely minute bristles outside the seam (see couplet 41)........................*M. dimidiata* sp. nov.

66. Second section of the costa at least one-third longer than the first; mesonotum yellow.....................................67

Second section of the costa never much longer than the first, at least less than one-third longer 68

67. Hair-seam of hind tibia forming a straight unbroken line . . . . *M. reversa* sp. nov.

Hair-seam of hind tibia bent outward at the middle, its apical half lying farther to the outside than the basal half . . . . *M. deflexa* sp. nov.

68. Front tarsi simple, not enlarged, or if enlarged, uniformly swollen 69

Second and following joints of front tarsi enlarged and flattened in the male; hypopygium very large, bent downward . . . . *M. patellipes* sp. nov.

69. Hair-seam of hind tibiæ (♀) forming a continuous, unbroken line 70

Hair-seam of hind tibia bent outward at the middle, its apical half lying further to the outside than the basal half (see couplet 56) . . . . male of *M. politifrons* sp. nov.

70. Front quadrate 71

Front considerably wider than high; preocellar row of bristles equidistant from the upper and lower margins of the front and forming practically a straight line . . . . . . *M. teoënsis* sp. nov.

71. Antial bristles as far from the eye-margin as from one another; male antennæ enlarged, front tarsi noticeably thickened, especially the first joint . . . . *M. inflaticornis* sp. nov.

Antial bristles much nearer to the eye-margin than to one another 72

72. Body black . . . . *M. perumbrata* sp. nov.

Mesonotum brownish or yellow; front usually mainly yellow (see couplet 67) . . . . *M. reversa* sp. nov.

OTHER PHILIPPINE SPECIES OF MEGASELIA

In addition to the species of Megaselia included in the preceding key there are four other species described from the Philippines.

Megaselia variata Malloch

Proc. U. S. Nat. Mus., vol. 43, p. 515 (1912).

This is apparently related to *M. setifrons* sp. nov. and *M. trisecta* sp. nov., but the wing venation is very different. The type locality is Manila.

Megaselia curtineura Brues

Journ. New York Entom. Soc., vol. 10, p. 6 (1909).

This species is similar to *M. brevineura* sp. nov., but the wing venation is different, the postantennal bristles are unequal and it is much lighter colored. The type locality is Manila.

Megaselia banksi Brues

Journ. New York Entom. Soc., vol. 10, p. 5 (1909).

Although the mesopleura is not described in the original description, it is bare and the species belongs to Megaselia *s. str.* It runs to *M. setifrons* sp. nov. in the key given on a previous page, but differs from that species in the wings, especially the length of the divisions of the costa. The type locality is Manila.

Megaselia scopifera sp. nov.

♀. Length 3.4 mm. Head and thorax dull brown, the antennæ blackened below; upper surface of abdomen black, the basal half of the second tergite dull yellow; apical margin of the second and fourth narrowly pale and of the other tergites faintly so; pleuræ and legs testaceous, the tips of the hind femora black; halteres black, with brown stalk. Wings hyaline, with a distinct yellowish tinge, especially in front of the third vein; heavy veins light brown, light veins very well pigmented. Frontal bristles very long; four equally strong and stout postantennals, the lower pair separated by about one-fourth the width of the front and the upper ones by one-third; antial bristles set slightly nearer to the middle line than the lowest lateral bristle (which is close to the eye) and at a level between the lower and upper postantennals; præocellar row of four equidistant bristles forming a straight transverse line; ocellar bristles very strong; front with a distinct median impressed line, slightly wider than high. Postocular cilia strong, the uppermost one enlarged, half as long as the lateral ocellar bristle which sets just in front of it; cheeks each with two strong bristles. Antennæ and palpi of moderate size, the latter with well developed bristling. Mesonotum long, with very fine hairs; one pair of weak dorsocentral bristles; scutellum with only two bristles. Mesopleura clothed above with minute black hairs and bearing a single long bristle at the extreme hind margin near the middle of the patch of hairs. Abdomen with all the tergites fully chitinized; second segment short, with a tuft of backwardly directed bristles at each side covering the lateral aspect; third tergite somewhat longer than the second; fourth narrower, quadrangular, nearly as long as the second and third combined; fifth much shorter, with a dense fringe of irregular stiff bristly hairs along the lateral and posterior margins; sixth apically with sparse bristly hairs; seventh covered with sparse, larger ones; eighth with a dense covering of backwardly directed ones. Middle and hind tibiæ with a double series of cilia, one on each side of the seam. On the hind tibiæ the cilia of the inner series are larger, about two-thirds the width of the tibia, and the outer series of smaller cilia extends only to the apical third; the space between the two series is a groove, destitute of hairs; tarsi very slender. Wings long and narrow; costal vein three-fifths of the wing length, its cilia very short and densely placed; first section of costa distinctly shorter than the second which is four times as long as the third; third vein forking at a wide angle, the second vein not quite so long as the third section of the costa; fourth vein short, evenly and rather strongly curved; fifth and sixth weakly bisinuate, seventh long, nearly straight.

Type from Angan Falls, Sibulan River (3,000 ft.), November 11, 1930 (C. F. Clagg).

This species resembles somewhat *M. atriclava* Brues from Formosa, but that species lacks the stiff bristly hairs at the apex of the abdomen. From *M. fortiuscula* Brues from Java, of which only the male is known it differs in venation, by the shorter costa and lower front. Among the other members of the genus hitherto described from this region I do not find any other species with which it might be confused.

Megaselia labialis sp. nov. (Fig. 2)

♂. Length 1.8–2.1 mm. Brownish yellow; front, antennæ, palpi, pleuræ and legs lighter and more or less testaceous; abdomen with a blackened transverse band including the third segment and less distinctly the apical part of the second and sides of the fourth. Front about quadrate, with distinct median impressed line, the ocellar tubercle black; four long, equal postantennal bristles, the lower pair separated by one-fourth the width of the front and the upper by one-half its width; antial bristles at the level of the upper postantennals and almost as near to the eye as the lowest line; præocellar bristles equidistant, in a line that is moderately convex below; ocellar bristles large. Antennæ small, with a pubescent arista as long as the head height; palpi with rather strong bristles along the lower edge. Proboscis with the labella forming a flattened, shield-shaped plate, concave below, convex and hairy above, almost as wide as the front and widely separating the palpi which lie at each side of it. Cheeks each with a stout bristle and several smaller ones extending upwards toward the antenna. Mesonotum subshining, rather long, with one pair of dorsocentral bristles and no distinct smaller bristles between them. Scutellum with two strong bristles. Second abdominal tergite lengthened, twice as long as the third, not bristly at the sides, other tergites about equal, the seventh somewhat longer and sharply narrowed apically. Hind tibia with a series of about eleven moderately long cilia inside the seam and a weaker series just outside the seam, extending nearly to the tip of the tibia; tarsi very long and slender. Wings long and narrow, with a slight yellowish cast; heavy veins light brown; light veins pale; costa about three-fifths the wing length, its cilia very short and closely placed; second section of costa distinctly shorter than the first and three times as long as the third; fork of third vein rather acute, the second vein nearly as long as the third section of costa; fourth vein sharply curved at base and straight beyond; fifth to seventh practically straight.

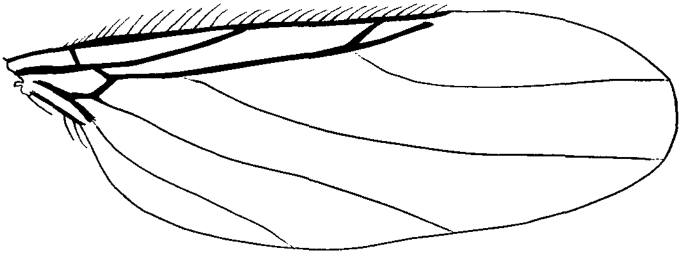

FIGURE 2. *Megaselia labialis* sp. nov., wing.

♀. Differs by its larger size (about 2.5 mm.) and more uniformly dark abdomen. There are only four completely formed abdominal tergites and a very small transverse one on the fifth segment. The proboscis lacks entirely the peculiar modification of the labella seen in the male. In some males the abdomen is considerably lighter or darker in color, but it usually shows the darker or black transverse band.

Type from the Galog River (5,000 ft.) Mt. Apo, Mindanao, Philippines, September 7, 1930. Seven other males and two females from the following localities: Galog River (5,000 ft.), Sept. 26–Oct. 22, 1930; Sibulan River (2,000 ft.), Oct. 20, 1930; Mt. Mayo (4–5,000 ft.), Jan. 30, 1931; Lalun Mts. (5,500 ft.) Bakrayan (8,000 ft.). This is similar to *M. fortiuscula* Brues from Java, but differs by the quadrate front.

Megaselia baroringensis sp. nov.

♀. Length 2.4 mm. Dark brown, abdomen black; pleuræ below and anterior legs lighter. Front black above, with the lower third light reddish brown; antennæ red brown; palpi pale yellow; scutellum darker than the mesonotum, nearly black; front legs testaceous, with the tarsi dark, middle and hind legs successively darker, the hind femora not blackened at tip. Wings with a brown tinge, the heavy veins light brown; halteres light brown. Front quadrate, with distinct median line; four postantennal bristles, the upper pair larger, twice as far apart as the lower ones and separated by about half the width of the front; antial bristles at the level of the upper postantennals, set next to the eye, directly below the lowest lateral bristles; præocellar row of four equidistant bristles, strongly curved downward medially; all bristles strong; front clothed with sparse hairs. Antennæ of moderate size; palpi with strong downwardly directed bristles along their lower margins; cheeks each with two large bristles and a series of much smaller ones upward to the antenna; mesonotum clothed with fine hairs which become bristle-like and more sparse before the scutellum; two dorsocentral bristles and two on the scutellum. Pleura above with fine appressed hairs and one long, backwardly directed bristle. Abdomen with six well chitinized tergites, the second scarcely elongated, with a few bristly hairs at each side. Apex of abdomen without conspicuous hairs or bristles. Legs rather slender; hind femora scarcely more than one-third as broad as long; hind tibiæ with two rows of moderately long bristles, those in the posterodorsal row longer, but less than the width of the tibia. Wings long and narrow; costa three-fifths the wing length; width of wing two-fifths its length; costa with dense, very short cilia; second section almost three-fourths as long as the first (17 : 24) and about one-third longer than the third (17 : 13), the cell formed by the fork of the third vein unusually long as the second vein is only one-half as long as the third section of the costa. Fourth vein straight except at extreme base, following practically straight, the seventh long.

Type from Baroring River (6000 ft.), November 8, 1930.

Megaselia nocturnalis sp. nov.

♀. Length 2.1 mm. Black, the palpi pale yellowish; legs brownish yellow, the hind pair not infuscated; front entirely black, slightly pruinose; antennæ reddish brown; abdomen more or less pruinose, especially on the third to fifth tergites; wings hyaline, with fuscous veins; halteres brownish testaceous. Front subshining, slightly higher than wide, with very minute hairs; median groove very finely impressed; four postantennal bristles of approximately equal size, the upper pair set level with the antial bristles, separated by one-third the width of the front, lower pair by one-sixth its width; antial bristle close to the eye, directly below the lowest lateral; median pair of præocellar bristles nearer to one another than to the lateral ones, the row nearly straight; all frontal bristles strong, but not very large. Antennæ small; palpi with moderate-sized bristles apically below; cheeks each with two bristles and a decreasing series above extending toward the antenna. Mesonotum subshining, finely hairy, with one pair of strong dorsocentral bristles and four small bristles disposed between them. Scutellum with two long bristles. Mesopleura with a patch of short appressed bristly hairs above and one very long bristle. Abdominal tergites 2–6 of about equal length, the second with several bristly hairs at each side; apex of abdomen without conspicuous hairs or bristles. Legs slender; the front tarsi, however, distinctly thickened apically. Hind tibiæ with two rows of cilia, those of the postero-dorsal row shorter than the width of the tibia and the bristles of the outer row much shorter and weaker. Wings long and narrow; costa reaching to slightly beyond the middle of the wing, its cilia very short and densely placed; first section longer than the other two together (23 : 18); second section one-half longer than the third (10 : 7); cell at fork of third vein rather long, the second vein strongly sloped, two-thirds as long as the third section of the costa; fourth vein slightly curved on basal third, straight beyond; following practically straight.

Type from Teo Ridge (6,500 ft.), September, 1930; paratype from the Galog River (5,000 ft.), October 8, 1930, taken in a trap lantern.

The outer row of setulæ on the hind tibiæ is very feebly developed and might easily be overlooked.

Megaselia claggi sp. nov.

♀. Length 2.5 mm. Black; the pleuræ brown below, with a yellowish brown area above the hind coxa; antennæ reddish; darkened at tips; palpi deep yellow; front legs yellow, middle pair slightly infuscated, hind pair strongly so, with the tibiæ almost black, except at base; wings faintly yellowish with light brown venation; halteres white with dark stalk. Front about quadrate, with median impressed line; four postantennal bristles, the lower pair much shorter than the upper ones and less than half as widely separated, the upper ones separated by scarcely more than one-third the width of the front, set at the same level as the antial bristles which are farther from the eye than the lowest lateral bristles; præocellar bristles forming a straight row close to the ocellar triangle, the median pair distinctly closer to one another than to the lateral bristle; ocellar row as usual; all the frontal bristles moderately strong. Antennæ of normal size; palpi with strong, closely set bristles; cheeks each with a large downwardly directed bristle, scarcely larger than the next three in the row that extends toward the antenna. Mesopleura with a long patch of fine, appressed hairs above and one large bristle. Mesonotum densely and finely hairy, the hairs larger and more scattered near the scutellum; two strong dorsocentral bristles without conspicuous bristly hairs between them; scutellum unusually wide and short, with two very long bristles. Abdomen broad, velvety black with the incisures between the tergites pale, the surface irregularly glaucous; six chitinized tergites, all of about equal length, the second entirely without bristly hairs at the sides; apex of abdomen without conspicuous hairs. Legs stout, particularly the hind tibiæ, all the tarsi slender. Hind femora nearly half as wide as long; their tibiæ with two rows of strong cilia, the postero-dorsal series of seven bristles about as long as the width of the tibia, the outer row similar and scarcely weaker. Costa extending to well beyond the middle of the wing (49 : 90), with very short, densely placed cilia; first section nearly one-half longer than the other two together (26 : 18), third about two-thirds as long as the second (7½ : 11); fourth vein slightly bent at base, straight beyond; following nearly straight; seventh long.

Type from Baroring River (6,000 ft.), November 8, 1930. This species resembles *M. lanceolata* Brues from Formosa, but differs in venation.

Megaselia trisecta sp. nov. (Fig. 3)

♀. Length 2.2 mm. Dark brown, the front lighter below, with the ocellar triangle black; mesonotum fuscous, the pleuræ lighter, especially the metapleura below; abdomen entirely black; antennæ reddish yellow, darker at tips; palpi clear yellow; front legs testaceous, posterior ones darker, especially the tips of the hind femora and tibiæ; wings slightly yellowish, the veins rather light brown; halteres brown. Front about quadrate, clothed with sparse hairs, median impressed line distinct. Four postantennal bristles of about equal size, the upper ones three times as far apart as the lower and separated by one-half the width of the front; antial bristles set at the level of the upper postantennals and distinctly further from the eye than the lowest lateral bristles; præocellar row curving slightly downward medially, its bristles equidistant. Antennæ of moderate size; cheeks each with two very strong downwardly directed bristles and several very much smaller ones forming a line that extends upward toward the antenna. Palpi of good size, but not noticeably enlarged, with a single series of strong bristles along the lower edge. Mesonotum subshining, minutely hairy, less densely so behind; one pair of dorsocentral bristles; scutellum broad and short, with two strong marginal bristles. Mesopleura with a patch of small appressed hairs and one long bristle above. Abdomen with all the tergites chitinized; second tergite with a series of about four noticeable bristles that extend obliquely backward placed along the lateral margin; third tergite noticeably elongated, considerably longer than the second; fourth very short; fifth elongated, as long as the third; tip of abdomen without noticeable hairs or bristles. Legs moderately stout, including the tarsi, except those of the middle legs which are very slender. Hind tibiæ with two rows of bristles, those of the postero-dorsal series nearly as long as the width of the tibia; those of the outer row clearly shorter, but still strong. Costa three-fifths the wing length (53 : 85); with very short and closely placed cilia; first section about as long as the second and third together (23 : 24), the third three-fifths as long as the second (9 : 15); fork of third vein not very acute, the second vein one-half as long as the third section of the costa; fourth vein very sharply curved at the base. straight beyond; fifth slightly bent near middle; sixth and seventh straight.

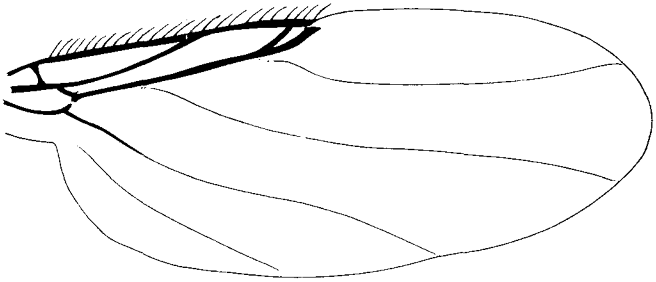

FIGURE 3. *Megaselia trisecta* sp. nov., wing.

Type from the Galog River (5,000 ft.), September 22, 1930.

Megaselia inflatipes sp. nov. (Fig. 4)

♂. Length 1.7–2.0 mm. Black, the thorax brown-black anteriorly and on the pleuræ; antennæ piceous; palpi brown; legs brownish-yellow; tips of hind femora, their tibiæ and tarsi darker; hypopygial lamella yellow. Wings rather strongly tinged with brown, the venation dark fuscous. Halteres black. Front slightly, but distinctly wider than high; shining, although slightly pollinose in certain lights; median frontal line very weakly indicated. Four postantennal bristles of nearly equal size; lower ones separated by one-sixth the width of the front; upper ones by one-third; antial bristles set well below the level of the upper postantennals and slightly farther from the eye than the lowest lateral bristles, which are themselves not quite so close as usual to the eye-margin; præocellar bristles equidistant, forming a row that is strongly bowed downwards medially. Antennæ of medium size, not distinctly enlarged; palpi with irregular, rather strong bristles below. Cheek with two strong bristles below and a series of about four very short ones extending upward toward the antenna. Mesonotum subshining, clothed with minute silken brown hairs; one pair of dorsocentral bristles and two very long scutellar bristles set unusually far apart. Mesopleura thinly hairy above, with one long backwardly directed bristle. Abdomen dull black above, the tergites indistinctly margined with whitish behind; second tergite not elongated, without noticeable bristles at the sides; sixth segment with scattered minute bristles at the sides and a transverse row of about eight just before the posterior margin. Hypopygium small, projecting

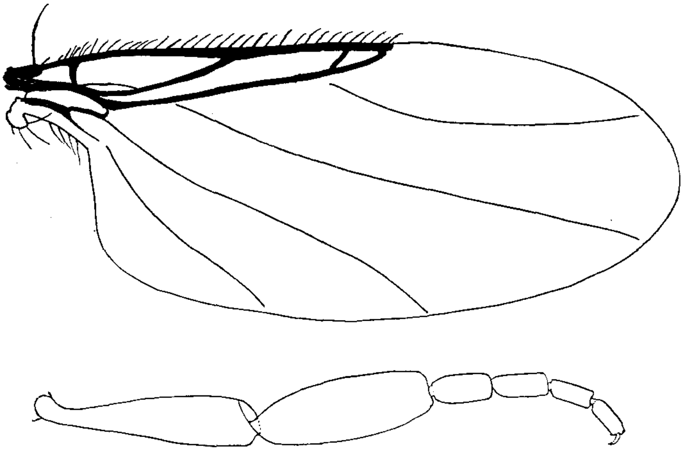

FIGURE 4. *Megaselia inflatipes* sp. nov. a, wing; b, front tarsus of male.

downward as three pieces, a shining black, blunt, quadrangular one on the left side and two clavate smaller ones on the right; sides of the seventh segment below with several small bristles near the posterior edge. Costa extending about to the middle of the wing, its cilia short, but not excessively so; first section of costa slightly longer than the second; third two-fifths as long as the second (28 : 25 : 10); furcation of third vein not very acute, the second vein rising sharply to the costa; fourth vein evenly and gently curved; fifth and sixth veins nearly straight, very slightly bisinuate; seventh slightly bent at the middle. Front metatarsus as broad or slightly broader than, and nearly as long as the tibia, its inner surface destitute of hairs, except along the sides; following joints noticeably widened, especially the second; hind tibia with only a single row of setulæ, these rather weak and much shorter than the width of the tibia.

Type from the Sibulan River (Angan Falls, 3000 ft.), Mt. Apo, November 11, 1930. Ten paratypes; two from the Sibulan River (4,000–8,000 ft.), Sept.–Nov., 1930; four from the Galog River (5,000 ft.), Nov., 1930; three from the Mainit River (6,000 ft.), Sept.; one from Teo Ridge (5,500 ft.), Sept. There is one other male from the Galog River in which the supra-antennal bristles are further apart, the upper ones separated by fully half the width of the front, but it seems otherwise essentially similar to the foregoing series.

Megaselia antennalis sp. nov. (Fig. 5)

♂. Length 1.3 mm. Mesonotum piceous; abdomen black, with narrow whitish margins on segments one to three; front and antennæ black; palpi pale yellowish; pleuræ piceous, somewhat paler below; legs brownish yellow, the hind femora slightly blackened at the tips; halteres black; hypopygium shining black, its lamella dark with paler tip. Front slightly wider than high, with conspicuously strong bristles; four equally large postantennal bristles, the upper pair twice as far from one another as the lower pair, occupying slightly more than one-fourth the width of the front, set a little higher than the antial bristles which are very close to and scarcely below the lowest lateral bristles; middle frontal row of bristles equidistant, in a straight transverse line. Antennæ oval, conspicuously larger than usual, the third joint as long as the width of the eye in lateral view; arista dorsal, weakly pubescent; palpi with rather short bristles near tips, bare elsewhere; cheeks each with a pair of strong, divergent bristles. Mesonotum subshining, rather coarsely hairy, with one pair of dorsocentral bristles; two large scutellar bristles and two weak hairs;

mesopleura with a group of small bristly hairs above and one backwardly directed bristle. Abdominal tergites with opaque surface, all of about equal length, except the fifth which is slightly shorter; second without conspicuous lateral tufts of hairs or bristles although the lateral margins of all tergites are more or less distinctly fringed with short hairs, these extending across the hind margin of the fifth and generally over the surface of the sixth. Hypopygium rather large, oval, with some bristly hairs below, bearing a large projection apically on the left side; this consists of a stout, centrally constricted base and a very slender apical part, extending at a right angle upwards and then curving toward the right side; right hand side of hypopygium with a short blunt process that extends dorsally toward the lamella. Front tarsi noticeably swollen, the first joint nearly as broad as the tip of the tibia and one-half its length; second to fourth joints also much broadened but successively less so, each twice as long as broad; hind tibiæ each with a posterodorsal series of moderately weak setæ and three or four transverse comb-like rows of bristles inwardly at tip. Costa barely half the wing length, its cilia of medium length; first section as long as the second and three times as long as the third (14 : 15 : 5); third vein ascending steeply to the costa; fourth vein evenly arcuate; fifth nearly straight; sixth sinuate; seventh weakly curved.

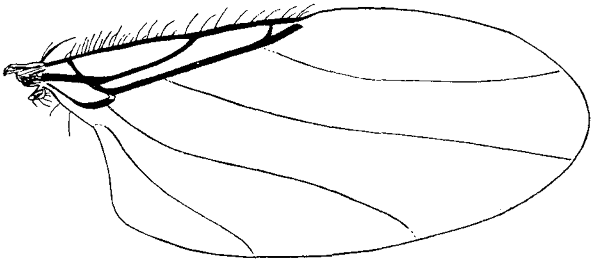

FIGURE 5. *Megaselia antennalis* sp. nov., wing.

Type from Lalun Mts., (5,500 ft.), Davao Province, Mindanao, Philippines, December 31, 1930. Paratype male from the Galog River, 5,000 ft., October 22, 1930.

This species is readily distinguishable by the strikingly enlarged antennæ.

Megaselia costipennis sp. nov.

♀. Length 2.8 mm. Head and thorax pale brownish yellow; front more or less blackened above, the antennæ and palpi pale yellow;

abdomen piceous above, the second tergite with a large yellow spot at each side and the first three tergites each with a narrow marginal yellow line; legs yellowish testaceous. Wings hyaline, with dark brown veins, except that the costa is very much paler brown; halteres black. Front quadrate, the median impressed line very faintly indicated. Four postantennal bristles, the lower pair very small and the upper pair, although conspicuously larger, are very much shorter than the other frontal bristles and separated by only about one-sixth the width of the front; antial bristles on a level with the upper postantennals, unusually near together, their insertions equidistant between the eye and median line of front; lowest lateral bristles close to the eye and far above the antial bristles; upper transverse row of four equidistant bristles bowed gently downwards medially, almost twice as far from the antial bristles as from the ocellar row. Antennæ small, more strongly ovate than usual, with the arista inserted much before the tip. Palpi small, with a few strong bristles apically below. Postocular cilia strongly enlarged below, the lower two very long; inner edge of eye with a series of about nine long, thin bristles extending from the lower corner to the level of the antennæ. Proboscis short, stout, but not strongly sclerotized, the lower oral margin forming a sharply raised curved edge. Mesonotum with one pair of very widely separated dorsocentral bristles. Mesopleura above with a small patch of fine bristly hairs and one long, backwardly directed bristle which is about as long as the greatest width of the hind tibia. Second to fourth abdominal tergites of about equal length, the second slightly bristly at the sides; fifth tergite somewhat longer, subtriangular, but with the apex narrowly rounded; sixth smaller, but of about the same shape; apical segments membranous. Legs rather stout, especially the hind pair; hind tibiæ with a single row of setulæ inside the seam; these are weak basally but become moderately strong apically. Costa reaching to about the middle of the wing, conspicuously thickened, the thickening beginning at the basal third of the first section and gradually tapering off beyond the tip of the first vein; widest part as thick as the length of the second vein; costal cilia short and closely placed. First section of costa barely shorter than the second, which is three times as long as the third (37 : 40 : 13). First, second and third veins not thickened; fork of the second quite acute, the second vein strongly oblique; fourth vein strongly bent at base, straight beyond, except for a sharp recurving at extreme tip; fifth slightly curved; sixth and seventh barely sinuate.

Type from the Sibulan River (3,000 ft.) at Angan Falls, Mt. Apo, Philippines, November 11, 1930 (C. F. Clagg).

This species is very distinct by the striking configuration of the thickened costa. The bristling of the head about the lower part of the eyes is also unusual. The form of the costa is very similar to that of *Phalacrotophora epeiræ* Brues. In a number of species of Megaselia a thickening of the costa occurs in the female also, but I know of no species where it is as in the present form.

Megaselia cultrata sp. nov.

♀. Length 1.5 mm. Front and mesonotum dark brown, the front lighter on the sides and below; pleuræ pale brown, the legs lighter, yellowish, with the posterior tibiæ blackened at tips; abdomen piceous above, with pale marginal lines on the tergites; ovipositor black; wings hyaline, with brown veins; halteres black; antennæ and palpi very dark brownish. Wings faintly infuscated, veins dark brown; halteres black. Front quadrate, its surface rather dull; only two postantennal bristles, separated by one-fourth the width of the front, the lower pair represented by two very minute bristly hairs; antial bristles as far from the eye as from the median line, set higher than the postantennals and below the lowest lateral bristles; middle frontal row of four equidistant bristles curving strongly downwards medially; all frontal bristles comparatively large and strong. Antennæ small, almost black, with a long slender arista. Palpi dark brown, with moderately long but weak bristles on apical half below. Cheeks with two divergent downwardly directed bristles; inner margin of eye with unusually long, thin bristles in a row extending upwards to the antennæ. Mesonotum strongly convex, with one pair of rather short dorsocentral bristles; scutellum with two large strong bristles and a pair of minute ones set further to the sides. Mesopleura with a patch of hairs above and one large bristle set near the bottom of the patch and extending to the root of the wing. Abdomen above with dull, velvety surface, except the extruded ovipositor which is subshining; quite sharply narrowed beyond the fourth tergite; basal five tergites of about equal length; the fifth very narrow, longer than broad at base and with a pair of discal bristles nearly as long as the tergite, and apically below the corner of the tergite on each side with a group of about four similar bristles; following segment short, tubular, the next and last nearly twice as long, forming a slender tubular ovipositor which is evenly curved upward from the base to tip and bears a few minute erect bristly hairs near the tip. Legs slender, setulæ of hind tibia in a single series inside of the seam, weakly developed, each one less than half the diameter of the tibia. Costa reaching barely beyond the middle of the wing, its cilia very short and closely placed; first section as long as the second, third about one-fourth as long (13 : 12 : 3); fork of third vein acute and as the third vein is bent upwards just beyond the fork the third costal section is very short; fourth vein evenly curved; fifth and sixth feebly sinuate; seventh long, nearly straight.

Type from the Sibulan River (7–8,000 ft.), Mt. Apo, Mindanao, Philippines, September 6, 1930 (C. F. Clagg).

Aside from the ovipositor, this species is noticeable on account of the very short third section of the costa.

Megaselia lalunensis sp. nov. (Fig. 6)

♂. Length 1.8–2.0 mm. A rather stout species. Black or piceous with the pleuræ brown, lighter below; legs yellowish brown with the hind femora blackened at tips; abdomen black, the base of the second tergite broadly and of the four following ones narrowly pale yellow, the second to fifth tergites also with very narrow pale posterior margins. Wings slightly infuscated, with dark veins. Halteres black. Front distinctly broader than high; four approximately equal postantennal bristles, the upper pair twice as far apart as the lower ones and separated by fully one-half the width of the front; antial bristles much lower than the upper postantennals, far below the lowest lateral bristles and rather near to the eye although not so close as the lateral bristles; middle frontal row of four equidistant bristles bowed downwards medially; all bristles of the front unusually large and stout. Antennæ brownish, not at all enlarged, with a long, very slender arista. Cheeks each with three stout bristles near the lower corner of the eye and several very small ones above these on the inner eye margin. Palpi pale yellow, with short, stout bristles apically. Mesonotum shining, with dense hairs anteriorly and sparse ones behind; one pair

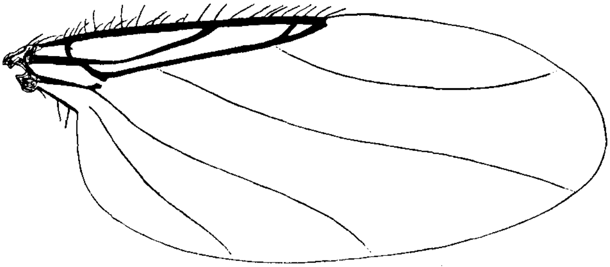

FIGURE 6. *Megaselia lalunensis* sp. nov., wing.

of dorsocentral bristles which are noticeably weaker than several strong bristles along the lateral edge of the mesonotum. Scutellum with two bristles. Mesopleura with a patch of sparse small bristly hairs and one large backwardly directed bristle about as long as the width of the patch. Second to fifth abdominal tergites gradually decreasing in length, bristly along the sides and the second with a few much stronger bristles; surface of these tergites with noticeable bristly hairs, larger on the apical segments. Hypopygium small, without any noticeable projections or spines, directed downwards and about the size and shape of the short lamella, except that it is sharply expanded and truncate at tip. Front legs with the tarsi slightly thickened, but not flattened; the tibia slender; first tarsal joint three-fifths as thick and four-sevenths as wide as the tibia, four times as long as thick; following joints each fully three times as long as wide. Hind legs rather stout, with a row of strong setulæ inside the seam, these nearly as long as the width of the tibia. Costa reaching to the middle of the wing, its bristles long and closely placed, equalling the distance between the costa and base of the third vein; first section as long as the other two combined; second nearly three times as long as the third (19 : 13 : 5); fourth vein gently and evenly arcuate; fifth practically straight; sixth bisinuate; seventh long, faintly sinuate.

Type from Lalun Mountains (5,500 ft.), Davao Province, Mindanao, Philippines, December 31, 1930 (C. F. Clagg). Paratype ♂ from the Mainit River, Mt. Apo (5,000 ft.), September 15, 1930 (C. F. Clagg).

Megaselia galogensis sp. nov.

♀. Length 2 mm. Light yellow, the front very much darkened, with the ocellar triangle black, abdomen above light fuscous; antennæ honey yellow or brown; palpi very pale yellow; hind femora blackened at tip. Wings quite distinctly brownish, the veins dark; halteres dark brown. Front about quadrate, with distinctly impressed median line; four postantennal bristles, the upper ones much stronger than the lower ones and nearly twice as far apart, occupying nearly one-third the width of the front; antial bristles midway between the upper postantennals and the eye margin and slightly lower; lowest lateral bristle above the antial and much nearer the eye margin; transverse frontal row of four equidistant bristles forming a line that curves downward medially and lies about midway between the ocellars and postantennals. Cheeks each with two downwardly directed bristles and a series of minute bristles extending upwards along the eye toward the antenna. Antennæ small; palpi strongly flattened, with long bristles below on the apical half. Mesonotum shining, sparsely hairy, with one pair of strong bristles. Mesopleura above with a patch of fine, sparse bristly hairs and one long backwardly directed bristle, set farther below the upper corner than is usual. Abdominal tergites one to five shining, of approximately equal length; sixth narrower and shorter. Hind tibia with a single series of setulæ inside the seam; these are of moderate size, distinctly shorter than the width of the tibia. Costa slightly more than half as long as the wing-length; first section one-quarter longer than the second, which is nearly two and one-half times as long as the third (15 : 12 : 5). Costal cilia very long, closely placed; fork of third vein acute, the second vein strongly oblique. Fourth vein weakly curved, somewhat more strongly so very near to its base; fifth vein slightly bent at the middle; sixth faintly bisinuate, seventh long and nearly straight.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, October 22, 1930 (C. F. Clagg).

This species presents no striking characters, but is readily distinguishable by the characters given in the key.

Megaselia alata sp. nov.

♀. Length 2–2.2 mm. Black; narrow lateral edges of mesonotum behind wings and broad posterior border of scutellum brownish yellow; antennæ and lower margin of front brown; palpi deep yellow; legs yellowish brown; wings slightly tinged with brown, with fuscous veins; halteres pale with brownish tinge. Front one-half higher than broad between the eyes, subshining, distinctly pollinose and with scattered minute hairs; bristles strong. Four postantennal bristles, the lower pair much smaller than the upper which in turn are distinctly smaller than the reclinate bristles; upper pair twice as far apart as the lower, occupying one-third the width of the front and placed clearly below the antials which are half as far from the eye-margin; lowest lateral bristles close to the eye, placed at the lower third of the front; frontal row of four in a straight, transverse line at the upper third of the front. Antennæ small, rounded, with a slender, nearly bare arista; palpi with stout bristles. Cheek with one stout downwardly directed bristle and a series of unusually long ones between this and the antenna. Mesonotum with one pair of strong dorsocentral bristles; scutellum large, nearly twice as wide as long, with two very strong bristles and a minute bristle on each side lateral to these. Mesopleura above with a patch of hairs and one strong backwardly directed bristle. Abdomen with four subequal tergites normally developed.

membranous beyond, the basal three subopaque, the fourth shining; second tergite with a tuft of bristly hairs at each side. Apex of abdomen (seventh segment?) more or less tubular, more than half as wide as the scutellum; extruded from this is the minute membranous tip with its cerci and beneath them a pair of small thin translucent horizontal whitish plates, each bearing about seven long bristles that spread out fan-shaped. The bristles are very stout at base, but finely attenuated toward the tip, about as long as the distance between the dorsocentral bristles. Legs moderately strong, the hind femora and tibiæ quite stout; hind tibiæ with a single row of closely placed setulæ inside the seam, each about as long as the width of the tibia. Costa extending slightly beyond the middle of the wing (5 : 9 : 5), with short, fine, closely placed bristles; first section of costa as long as the second and third together, the third nearly one-third as long as the second (21 : 16 : 5); fourth vein weakly curved at the base, straight beyond; fifth practically straight; sixth feebly sinuous, seventh long, very gently curved.

Type from the Mainit River (5,500 ft.) Mt. Apo, Mindanao, Philippines, September 14, 1930. Two paratypes from the Galog River (5,000 ft.), October 21 and the Sibulan River (7,000–8,000 ft.), September 6.

This species is characterized by the very peculiar fan-shaped bristling of the abdomen. The bristles may be partly withdrawn into the apex of the abdomen where they lie ventral to the extreme tip and its pair of cercus-like appendages.

Megaselia mainitensis sp. nov.

♀. Length 1.7 mm. Black; the legs pale brownish yellow, the hind pair darker, especially on the external side of the femora and tibiæ; antennæ brown, blackened on apical portion; palpi light yellow; wings hyaline, with dark veins; halteres pale brown, much lighter than the body. Front between one-third and one-quarter higher than wide, its surface subshining and scarcely hairy, but with the lower part whitish pollinose; median impressed line distinct; four proclinate bristles, the lower pair half as far apart as the upper ones which occupy somewhat less than one-third the width of the front; antial bristles well removed from the eye, set lower than the upper postantennals; lowest lateral bristles halfway between those of the frontal row and very close to the eye; frontal row of four equidistant bristles forming a straight transverse line. Antennæ small, with the arista nearly bare; palpi with long, but not stout bristles; cheeks each with a divergent pair of large bristles and a row of short ones extending upwards toward the antenna. Mesonotum with two dorsocentral bristles and several rather strong appressed bristles between them; scutellum with two long, stout bristles. Mesopleura with a patch of short hairs above and one long, backwardly directed bristle. Abdominal tergites of about equal length, six of them fully chitinized. Hind tibiæ with a single row of setulæ inside the seam, these rather stout and about as long as the width of the tibia. Costa extending to about the middle of the wing, its bristles very short, delicate and densely placed; first section of costa as long as the second and three times as long as the third (15 : 15 : 5); fork of third vein acute; fourth vein evenly bent, fifth gently curved; sixth slightly sinuate; seventh long.

Type from the Mainit River (5,500 ft.), Mt. Apo, Mindanao, Philippines, September 14, 1930 (C. F. Clagg).

This species is most similar to *M. sibulanensis,* but differs in the narrower front and much shorter first costal section.

Megaselia sibulanensis (Fig. 7)

♂. Length 1.4 mm. Black, the pleuræ very dark brown; posterior legs piceous with the tarsi pale brown; four anterior legs pale, blackened only on the femora; antennæ dark brown; palpi deep yellow; wings hyaline with dark veins; halteres pale. Front about as wide as high, with very long stout bristles, four postantennal bristles, the lower ones half as far apart as the upper pair which occupy one-third the width of the front; antial bristles set much below the upper postantennals and midway between them and the eye; lowest lateral bristle close to the eye and on a level with the upper postantennals; upper frontal row of four equidistant bristles forming a line that is bowed downwards medially. Antennæ small, with a long, rather strongly pubescent arista; palpi with long, strong, closely placed bristles on the apical half below; cheek with two strong downwardly directed bristles. Mesonotum with one pair of small dorsocentral bristles, very finely pubescent anteriorly, more coarsely so behind; scutellum with one pair of long, stout bristles. Mesopleura above with a patch of sparse hairs and one long, backwardly directed bristle near the lower edge of the patch. None of the abdominal tergites elongated, of about equal length, except the fifth which is noticeably shorter. Hypopygium visible from above as a rounded, subtriangular shining protuberance, about as long as the sixth tergite; seen from the side it is simple, small with pruinose surface and a few short scattered bristles; lamella yellow, short. Hind tibia with a series of rather short setulæ inside the seam, these widely spaced apically; outside the seam the hairs are longer, but do not form a second row of setulæ; all joints of front tarsi cylindrical, not enlarged nor flattened, although not so slender as in some species. Costa extending to the middle of the wing, with long, widely spaced bristles; first section of costa barely longer than the second which is three times as long as the third (11 : 10 : 3); fork of third vein unusually acute; fourth vein gently curved throughout; fifth slightly bent on basal half; sixth and seventh feebly sinuous.

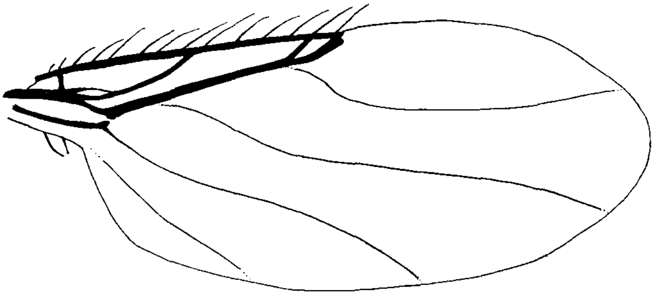

FIGURE 7. *Megaselia sibulanensis* ♂, sp. nov., wing.

♀. Larger, length 1.7–2.0 mm. Essentially like the male, but the thorax is lighter, with the mesonotum piceous and the pleuræ brown. The long bristle on the mesopleura is noticeably shorter, although still very conspicuously longer than the hairs.

Male type from the Sibulan River (3,000 ft.) at Angan Falls, Mt. Apo, Mindanao, Philippines, November 11, 1930 (C. F. Clagg). One male paratype from the Mainit River (5,500 ft.), October 7, and two females from the Sibulan River (7–8,000 ft.) September 21 and the Galog River (5,000 ft.), October 22.

Megaselia perspinosa sp. nov. (Fig. 8)

♂. Length 1.7–2.0 mm. Black; legs and pleuræ piceous, the front legs fuscous; palpi and hypopygial lamella yellowish brown; wings hyaline, with dark veins; halteres black or piceous. Front one-fifth broader than high, with strongly impressed median groove and very large stout bristles; four postantennal bristles of about equal size, the upper ones twice as far apart as the lower, occupying fully one-third the width of the front; antial bristles close to the eye, on a level with the lower postantennals and far below the lowest lateral bristles which are on a level with the antials; upper frontal bristles equidistant from one another, forming a nearly straight, transverse line. Antennæ slightly enlarged, as long as half the width of the front; palpi small, but with unusually strong bristles; two stout, divergent bristles on each cheek and a series of very small ones extending from them to the base of the antenna; another, equally strong pair on the propleura next to the front coxa. Mesonotum subshining, densely hairy above, but without enlarged bristly hairs between the single pair of dorsocentral bristles. Scutellum with six marginal bristles, one very long one at the middle of each side, a smaller pair nearer the middle and another small pair near the extreme lateral angle. Mesopleura above with a patch of rather coarse and sparse hairs near the bottom of which is a very strong, single backwardly directed bristle. Abdominal tergites of rather even length, the first two slightly longer and the sides of the second bearing a patch of bristly hairs; margin of fifth tergite and surface of the sixth with sparse bristly hairs. Hypopygium bearing below at apex a shining blade-like projection that extends backwards toward the median line. Legs rather stout; front tarsi slightly thickened, the first joint two-thirds as long as the tibia, those following three to four times as long as thick; hind tibia with a single row of setulæ inside the seam, on the apical half these are distinctly shorter than the width of the tibia; inner surface of tibia at tip with several transverse rows of comb-like scaly hairs. Costa extending very slightly beyond the middle of the wing, its cilia moderately short, densely placed; first section of costa about as long as the second and third together, third slightly more than one-third the length of the second (18 : 14 : 5); fork of third vein acute; fourth vein more noticeably curved at the base; fifth faintly sinuate; sixth and seventh more strongly so, especially the sixth.

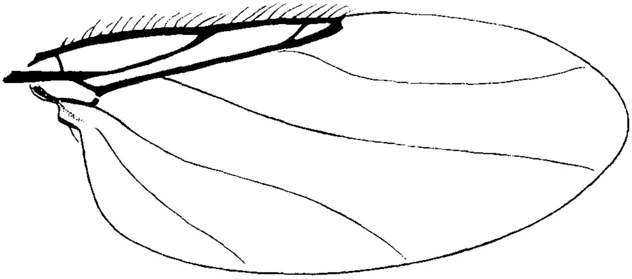

FIGURE 8. *Megaselia perspinosa* sp. nov., wing.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, September 6, 1930 (C. F. Clagg). Two paratypes, one from the Galog River (5,000 ft.) September 26, and the other from the Mainit River (5,000 ft.) September 24.

This species resembles *M. antennalis* but the front tarsi are weakly thickened and the configuration of the heavy veins in the wing is very different; the six bristles on the scutellum is an unusual, although by no means unique character. The hypopygial process is blade-like, not geniculate as in *M. antennalis*.

Megaselia quadrispinosa sp. nov.

♂. Length 1.75 mm. Head, thorax and legs brownish yellow; abdomen and halteres black; front honey yellow, the antennæ rather dark yellowish brown and the palpi clear yellow; mesonotum dull brownish yellow, the pleuræ very pale, almost testaceous below; the legs slightly darker than the pleuræ, with the hind femora blackened at tips; wings very distinctly brownish, with dark veins. Front about one-fourth wider than high; two large postantennal bristles separated by about one-sixth the width of the front, the lower pair practically absent, being indicated only by two minute bristly hairs; antial bristles set lower than the postantennals, each one as far from the eye as from the median line and set considerably below the lowest lateral bristle which is further from the eye than usual; frontal row of four nearer to the ocelli than usual, the median pair nearer to one another than to the lateral bristle. Antennæ of normal size, with a rather short, thick arista. Palpi with slender, but not shortened bristles below on apical half. Cheeks each with two strong divergent bristles below and a series of about four long slender ones extending upward to the antenna. Mesonotum more coarsely and sparsely hairy behind, its surface subshining. Scutellum long and narrow, with strongly sloping sides; four long, subequal scutellar bristles forming a rather close pair near the middle of each sloping lateral edge. Mesopleura above with a small patch of scattered hairs and one stout backwardly directed bristle set toward the lower part of the patch. Abdomen with the second tergite longest, third to fifth gradually shorter; sixth much narrower, clothed with scattered small bristles and margined behind with about six small bristles each about as long as the tergite; hypopygium small, globose. Hind tibia with the dorsal seam quite distinctly angulately bent before the middle, with a single row of rather weak bristles inside the seam. Costa reaching to the middle of the wing; its first section longer than the other two together, the third very short, little more than one-third as long as the second (18 : 11 : 4); costal bristles short and very closely placed; fork of third vein short, acute, forming a very small cell; fourth vein very weakly curved, with briefly recurved base and apex; fifth and sixth sinuate; seventh long, feebly curved.

Type from Lalun Mts. (5,500 ft.), Davao Province, Mindanao, Philippines (C. F. Clagg).

This species is striking on account of the absence of the lower postantennal bristles, broad front, quadrisetose scutellum, angulate hair-seam on hind tibia and the greatly lengthened first section of costa.

Megaselia bakeri sp. nov.

♀. Length 1.7 mm. Brownish yellow, the abdomen darker, becoming black beyond the fifth segment; wings hyaline, with brown venation; halteres brown, darker than the body. Front about one-fourth wider than high; only two postantennal bristles well developed, the lower pair very small; upper ones separated by about one-sixth the width of the front, barely above the antial bristles which are equidistant from the eye and median line; lowest lateral bristles well above the antials and not as close to the eye as usual; four upper frontal bristles forming a straight transverse row with the median pair slightly nearer to one another than to the lateral bristle, this row placed higher on the front than is usual. Antennæ small, with a densely pubescent arista. Palpi small, elongate and narrowed to a rather acute apex; below with moderately strong bristles. Proboscis projecting between the palpi and about as long as the latter, the oral opening large, with a strongly raised margin. Cheeks each with three strong bristles and several shorter ones extending upwards toward the base of the antenna. Mesonotum shining, thinly pubescent. Scutellum with four marginal bristles, the lateral one on each side shorter, but very well developed. Abdomen with the second tergite much lengthened, about one-half longer than the third, conspicuously bristly along the sides; third to fifth tergites subequal; sixth much narrowed and slightly longer, sparsely clothed with short bristles and bearing some longer ones apically; apical segment slightly projecting from within the apex of the sixth as a short strongly compressed structure which probably acts as an ovipositor. Mesopleura above with a patch of scattered small hairs and one large strong, backwardly directed bristle near the lower posterior edge of the patch. Hind tibiæ with a single series of weak bristles inside the seam. Costa reaching well beyond the middle of the wing (4 : 7 : 5), its bristles short and closely placed; first section of costa almost as long as the second and four times as long as the third (16 : 17 : 4), the cell formed by the fork of the third vein very small; fourth vein evenly curved; fifth strongly sinuous; sixth sinuous apically; seventh curved gently.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, October 22, 1930 (C. F. Clagg).

This species is strikingly similar to the preceding, especially in the shape and chætotaxy of the front. However the wing venation is so conspicuously different that I cannot believe that the two may be sexes of the same species. This is named in memory of Prof. C. F. Baker in recognition of his contributions to the entomology of the Philippines.

Megaselia pectinata sp. nov. (Fig. 9)

♂. Length 2.7 mm. Black or piceous with parts of the abdomen and the legs lighter; wings hyaline. Front black, antennæ dark brown; thorax above black, the edges of the mesonotum brown; pleuræ black above, honey yellow below; legs pale yellowish testaceous, the front tarsi light brown; hind femora black at tips and the hind tibiæ considerably darkened; abdomen above black, with the base of the first tergite, a pale median basal spot on tergites 2–5, and the narrow hind margins of tergites 1–5, fulvous; hypopygial lamella pale yellow; halteres pale brown, with a small black spot at tip. Front large, quadrate, the ocellar tubercle scarcely raised and the median line indistinctly impressed; four postantennal bristles, the upper ones larger than the lower, about twice as far apart and occupying distinctly more than one-third the width of the front; antial bristles set practically at the lower margin, not far removed from the eye; lowest frontal bristle next to the eye, well above the upper postantennals;

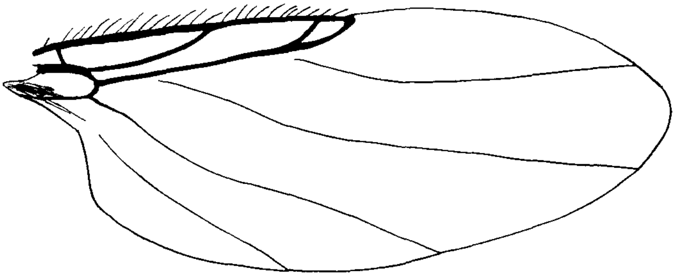

FIGURE 9. *Megaselia pectinata* sp. nov., wing.

upper frontal row of four forming a row that is strongly curved downwards medially. Antennæ of moderate size. Cheeks each with two very long bristles and a series of shorter ones extending upwards to the antenna. Mesonotum large, shining, thinly pubescent, with one pair of long dorsocentral bristles; scutellum large and broad, twice as wide as long, with a large bristle near each side and just lateral to this near the lateral angle a much smaller bristle. Abdominal tergites of approximately equal length except that the sixth is slightly longer; slightly bristly along the sides and faintly so on the posterior margins of the tergites, those on the sixth more conspicuous. Mesopleura hairy above, with two or three of the hairs along the posterior edge clearly longer and bristle-like although not large as in the species with a single large bristle in this position. Front tarsi greatly swollen, the first joint nearly as long as and about as thick as the tibia; second joint very stout and the following less so although much thicker than usual. Hind tibiæ with a row of strong setulæ inside the seam and a second, weaker row outside the seam, the latter series not extending to the tip of the tibia. Costa extending to the middle of the wing, its bristles very short and dense; first section of costa as long as the other two together, the third about one-third the length of the second (21 : 15 : 6); fork of third vein very acute; fourth vein only slightly curved, lying much nearer the costal margin than is usual; fifth feebly curved at base; sixth and seventh nearly straight.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, November 4, 1930 (C. F. Clagg).

This is a very distinct form on account of the form and chætotaxy of the front, enlarged front tarsi, mesopleural bristling and tibial setulæ.

Megaselia pilifera sp. nov.

♂. Length 1.3 mm. Black; palpi honey yellow; legs brown, the front pair lighter, more honey-yellow; antennæ piceous. Front very slightly higher than broad, with distinct tubercle and median groove. Four postantennal bristles of approximately equal size, the upper pair twice as far apart as the lower, occupying fully one-third the width of the front; antial bristles set very low and close to the eye-margin, well below the upper postantennals; upper frontal bristles forming a nearly straight transverse row midway between the lower ocellar and the upper postantennal bristles. Antennæ small; palpi with very long dense bristles below on the apical half. Cheeks each with three strong divergent bristles and a series of short ones extending thence toward the base of the antenna. Mesonotum dull, with unusually strong bristles along the lateral margin; one pair of dorso central bristles; scutellum narrow, subtriangular, with a single, strong bristle on each side. Abdomen dull black, with the tergites of approximately equal length, practically destitute of hairs except for a marginal row of bristle-like hairs at the apex of the sixth tergite. Hypopygium small, simple, pleura above with a patch of short hairs, the patch small however, as it does not extend so far forward as usual. Front tarsi considerably thickened but much less strongly so than in the preceding species; first tarsal joint a little more than half as long as the tibia and at least one-third narrower than the tibia; second tarsal joint less than twice as long as thick. Hind tibiæ with a row of strong setulæ inside the seam and a second row of shorter ones outside the seam, this row not quite complete apically. Costa reaching to about the middle of the wing, its bristles long, but closely placed; first section of costa about equal to the second, the third only about one-fourth the length of the second (11 : 11 : 3); fork of third vein acute, forming an unusually small cell; fourth vein gently and evenly curved; fifth feebly bent before the middle; sixth and seventh practically straight.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 8, 1930 (C. F. Clagg).

This species is similar in many respects to the previous one, but is much smaller in size and obviously distinct by the form and chætotaxy of the front, less strongly swollen front tarsi and mesopleural bristling.

Megaselia humeralis sp. nov.

♀. Length 1.7 mm. Black, legs yellowish brown; front yellowish along the lower margin; antennæ fuscous; palpi pale yellow; humeri of thorax yellowish brown and pleuræ also stained with brown below. Wings hyaline, with a weak brownish cast, the veins dark. Halteres pale, whitish, although more or less darkly stained in places, especially on the stalk. Front quadrate, sparsely pubescent and strongly pruinose below; ocellar tubercle strongly elevated, median frontal groove distinct, but extremely delicate; four moderately large, subequal postantennal bristles, the upper pair thrice as far apart as the lower ones, occupying considerably more than one-third the width of the front; antial bristles almost as near to the eye as the lowest lateral bristles and far below them, on a level with the upper postantennals; upper row of four frontal bristles equidistant, forming a straight line unusually high on the front, fully three times as far from the upper postantennal bristles as from the median ocellus; the lower lateral bristles are also set much higher than is usual. Antennæ small, with delicate arista; palpi with moderately strong bristles below. Cheeks each with three moderately large, divergent bristles below and a series of several smaller ones extending upwards toward the antennæ. Mesonotum subshining, with two strong, rather approximated dorsocentral bristles. Scutellum moderately broad, with two large marginal bristles set rather close together. Mesopleura above with a patch of short hairs, but without any noticeably larger hairs or bristles. Abdomen above subopaque, the tergites of about equal length, weakly sclerotized and bare except for a small group of bristly hairs at the side of the second segment. Hind tibia with an inner row of long, but weak and widely spaced setulæ inside the seam and a series of much smaller ones outside the seam; although small, the latter are clearly bristles and not hairs. Costa reaching well beyond the middle of the wing (37 : 67); first section of costa longer than the other two together, the second section slightly more than twice as long as the third; fork of third vein obtuse, the second vein rising so sharply to costa that it is only about half as long as the last section of the third vein; fourth vein practically straight; fifth weakly curved medially; sixth and seventh nearly straight.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 9, 1930 (C. F. Clagg).

Megaselia tinctipennis sp. nov. (Fig. 10)

♂. Length 1.9 mm. Black, the palpi and front legs beyond the knees yellowish brown; wings strongly infuscated, with very dark veins; halteres black. Front quadrate, the ocellar tubercle and median frontal line distinct; surface opaque; bristles strong. Four postantennal bristles of nearly equal size, the upper ones very widely separated, occupying distinctly more than one-third the width of the front; lower ones less than half as far apart as the upper ones; antials on a level with the lower postantennals, close to the eye; lowest lateral bristles forming with the upper postantennals a straight transverse row; upper frontal row of four equidistant bristles forming a line that curves downward slightly at the middle. Cheeks each with three strong, divergent bristles and a dense series of long slender ones extending up toward the antenna. Antennæ small, with long, thinly pubescent arista; palpi small, with moderate bristles below on apical half. Mesonotum subshining, rather densely hairy, especially behind, with one pair of rather weak dorsocentral bristles; scutellum broad, with one pair of strong bristles and a bristly hair just lateral to each of these. Abdomen dull velvety black, the second and fourth tergites noticeably lengthened; second with a small tuft of bristles laterally at apex; and the following segments with some scattered bristly hairs along the lateral margins. Mesopleura above with a patch of rather good-sized and sparse hairs, none of which are noticeably larger than the others. Front tarsi slightly stouter than usual, but not noticeably swollen or enlarged; hind tibiæ with a series of short, but stout and closely placed setulæ inside the seam and a second series of much shorter ones outside the seam present only on the basal half of the tibia. Costa extending distinctly beyond the middle of the wing, with moderately long, closely placed bristles; first section of costa nearly as long as the second and third sections together, the third about one-third as long as the second (17 : 14 : 5); fourth vein curved at extreme base, very gently so beyond and recurved at tip; fifth sinuous basally; sixth and seventh each feebly sinuous.

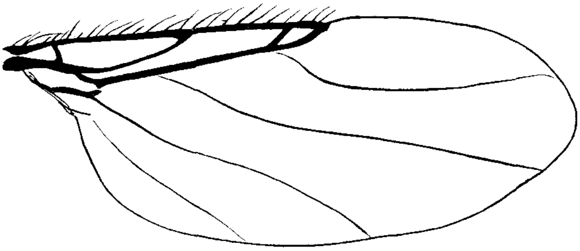

FIGURE 10. *Megaselia tinctipennis* sp. nov., wing.

♀. Length 2.0 mm. Essentially like the male, but with the halteres brown instead of black and with the outer row of bristles on the hind tibia not quite so small and continuing more or less distinctly to the tip of the tibia.

Type from the Galog River (7–8,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 6, 1930 (C. F. Clagg). Also eight other males from the Galog River, Sept.–Nov. and Baroring River (7,000 ft.) Nov. 7–8. One female from the Galog River, Sept. 5.

Megaselia umbrosa sp. nov.

♀. Length 2.0 mm. Black, the pleuræ piceous below; front legs and middle ones beyond the femora brown; palpi yellowish brown; wings considerably infuscated; halteres white. Frontal bristles long and stout; front quadrate, with strongly raised ocellar tubercle and weak median impressed line. Four equally strong postantennal bristles, the upper pair separated by one-third and the lower ones by one-fifth the width of the front; antial bristles set distinctly above the level of the lower postantennals and well away from the eye; lowest lateral bristles next to the eye at the level of the upper postantennals; bristles of upper frontal row equidistant, forming a line that is weakly bent down medially. Antennæ small, with long, noticeably pectinate arista; palpi small, strongly bristled below on apical half; cheeks each with four large bristles below and a series of much smaller ones extending up toward the antenna. Mesonotum shining, with rather conspicuous minute hairs, especially behind; one pair of dorsocentral bristles and four long, equally strong marginal bristles on the scutellum, which is twice as wide as long. Mesopleura with a patch of sparse hairs above of which two along the posterior edge below are longer although not approaching in size the long bristle seen in some species in that they are no longer than the width of the patch of hairs. None of the abdominal tergites noticeably elongated, their surface subshining and sparsely clothed with short hairs; all the tergites fully sclerotized; terminal appendages pale, soft. Hind tibiæ with two rows of bristles, the row inside the seam complete, its stout bristles nearly as long as the width of the tibia; outer row composed of very short bristles which become obsolete on the apical half of the tibia; inner side of tibia at apex with four or five transverse rows of short comb-like bristles. Costa extending slightly beyond the middle of the wing, with long and closely placed bristles which are about as long as the distance between the costa and third vein; first section of costa barely shorter than the second which is nearly three times as long as the third (16 : 17 : 6); fourth vein curved basally, nearly straight beyond and recurved at tip; fifth vein curved before the middle, straight beyond; sixth and seventh nearly straight.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 24, 1930 (C. F. Clagg).

This species is similar to the preceding, but the costal bristles are much longer, the wings not so strongly infuscated, the halteres white and there are four large scutellar bristles.

Megaselia curtipes sp. nov.

♀. Length 1.2 mm. Black; pleuræ piceous, the trochanters pale yellow and the legs dark brown with the front pair yellow; antennæ dark fuscous; palpi honey yellow. Wings hyaline, the veins rather light brown. Front quadrate, with raised ocellar tubercle and deep median groove. Four postantennal bristles, the upper pair considerably the larger, separated by fully one-third the width of the front; lower pair by one-sixth the frontal width; antial bristles midway between the level of the lower and upper postantennals and well removed from the eye; lowest lateral bristles well above the upper postantennals, next to the eye; upper frontal series of four equidistant, forming a line strongly curved downwards medially. Cheeks each with three long, divergent downwardly directed bristles and a series of closely placed delicate bristles extending upwards to the antenna. Antennæ small, with strongly pubescent arista; palpi with moderately stout bristles on the apical third. Mesonotum subshining, more sparsely hairy than usual; one pair of dorsocentral bristles; scutellum with a single pair of long, stout bristles. Mesopleura above with a small patch of sparse hairs, none of which are at all lengthened. Front tarsi noticeably shortened; slightly widened also, the first joint less than half as thick as the tibia. Hind tibiæ with two rows of bristles, one inside the seam composed of widely spaced bristles which are very short basally and become about two-thirds as long as the width of the tibia apically; the row outside the seam composed of much shorter bristles of even length, but this row extends only to the apical third of the tibia; hind tibia internally at tip with two very short transverse rows of comb-like bristles. Abdominal tergites fully sclerotized, none of them noticeably lengthened; sides of the second tergite without bristles; surface of abdomen above sub-shining. Costa reaching to the middle of the wing, with moderately long, rather sparsely placed bristles; first section of costa slightly shorter than the second, which is about three times as long as the third (11 : 12 : 4); fork of third vein very acute, the cell thus formed small and narrow; fourth vein curved basally, nearly straight beyond; fifth weakly bent at the middle; sixth faintly sinuate; seventh long, straight.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 24, 1930 (C. F. Clagg).

Megaselia debilitata sp. nov.

♀. Length 2.2 mm. Black, the humeri brown; pleuræ piceous; palpi and front coxæ pale yellowish; front legs yellowish brown, middle legs darker and the hind pair dark brown; halteres brown; wings very slightly infuscated, with fuscous venation. Front quadrate, with well defined ocellar tubercle and median frontal groove; four large, equal postantennal bristles, the upper pair separated by fully one-third the width of the front and the lower pair by one-sixth its width; antial bristles set at a level midway between the upper and lower postantennals, next the lower margin of the front, but well separated from the eye; lowest lateral bristles slightly above the upper postantennals; upper frontal bristles equidistant, forming a row that curves downward very strongly at the middle, the median pair set very much lower than the lateral bristles. Antennæ small. Palpi with very strong bristles below at tip, but those just beyond the middle much weaker. Cheeks each with four strong bristles directed downwards and forwards and a very closely set series of thin bristles above these, extending upwards toward the antennæ. Mesonotum subshining, its hairs large and bristle-like near the scutellum; one pair of strong dorsocentral bristles; scutellum rather long and narrow, subtriangular, with a single pair of strong bristles. Mesopleura above with a patch of sparse hairs. Abdomen dull black above, the tergites of about equal length. Front tarsi slightly stouter than usual. Hind tibiæ with two series of bristles; those inside the seam rather widely spaced, shorter than the width of the tibia; those of the outer row much shorter and more closely placed, obsolete on the apical third of the tibia; hind tibia at tip with three transverse rows of comb-like bristles on the inner surface. Costa extending slightly beyond the middle of the wing, with moderately long, closely placed bristles; first section of costa slightly longer than the second; second less than three times as long as the third (18 : 16 : 6). Fourth vein curved more strongly basally, nearly straight beyond and recurved at extreme apex; fifth vein feebly sinuous; sixth more strongly so; seventh long, nearly straight.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, October 22, 1930 (C. F. Clagg).

This species is quite similar to the preceding, but is much larger, the relative length of the costal sections is different and the costal bristles shorter, the postantennal bristles are of equal size. Considering these differences, I do not feel that the two could be considered conspecific.

Megaselia conspicua sp. nov.

♀. Length 1.9 mm. Black, with the fourth and following tergites orange yellow and the entire venter somewhat paler yellow; palpi and legs deep brown, except the front pair which are brownish yellow; wings subhyaline, with a slight brown tinge, veins very dark brown; halteres fuscous. Front quadrate, its surface shining, with strongly elevated ocellar tubercle and very conspicuous median groove; four postantennal bristles, the upper pair large occupying scarcely more than one-fifth the width of the front; lower pair very small and close together; antial bristles set very little below the level of the lowest lateral bristle, well inward from the latter, but closer to it than to the upper postantennals; four equidistant bristles in the upper frontal row forming a nearly straight line near to the ocelli. Antennæ small, with long, pubescent arista; palpi very small, but with long bristles below on apical half. Proboscis short, broad, spoon-shaped, heavily sclerotized and projecting slightly in front of the oral margin. Mesonotum subshining, finely pilose; one pair of small dorsocentral bristles with several bristly hairs between them; scutellum subtriangular, with a single pair of unusually long bristles. Surface of abdomen opaque; tergites subequal, except that the second is noticeably elongated, fully twice as long as the third; sixth and following tergites membranous, not sclerotized. Mesopleura above with a patch of minute bristly hairs. Front tarsi moderately slender, although stouter than those on the other legs; hind tibiæ with a single series of rather short and closely placed bristles inside the seam, at the tip with two short transverse rows of comb-like bristles on the inner side. Wings short and broad, the costa extending to the middle; costal bristles rather long and closely placed; first section of costa as long as the second, which is three times as long as the third; first and third veins unusually far from the costa, so that the heavy veins occupy a broader space than usual; fork of third vein acute, the cell thus formed small and acutely pointed basally; fourth vein weakly curved, somewhat more strongly so basally; fifth and sixth each strongly sinuate; seventh nearly straight.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 14, 1930 (C. F. Clagg).

Megaselia fulvicauda sp. nov.

♀. Length 3.0 mm. Black, with the palpi and four anterior tibiæ and tarsi brown; abdomen with tergites four to six orange-yellow and the entire venter a paler, but quite brilliant yellow. Wings slightly tinged with yellowish, the venation brown. Front quadrate or slightly wider than high, with well developed ocellar tubercle and median frontal groove, its surface shining and with few hairs; four nearly equal postantennal bristles, the upper pair separated by one-third, and the lower pair by one-fifth the width of the front; antial bristles set close to the eye, midway between the level of the upper and lower postantennals; lowest lateral bristles well above the antials; upper frontal bristles forming a line deeply bent downwards medially which is parallel with one formed by the bases of the antial and lowest lateral bristles. Antennæ small, with long, very thin arista. Palpi with sparse, but unusually long bristles. Cheeks each with two very long, downwardly directed bristles and a closely set series of long bristly hairs above these, extending upwards to the antennæ. Mesonotum subopaque, with unusually delicate short hairs; one pair of dorsocentral bristles. Scutellum with four large bristles, the median pair especially long. Surface of abdomen dull, the tergites all of approximately equal length, the second with a few short bristles at each side. Mesopleura with a patch of hairs above, one or two of which near the lower posterior edge are slightly larger than the others. Hind tibiæ with a single row of bristles behind, inside the seam these are rather widely spaced and nearly as long as the width of the tibia; inner surface of tibia at tip with about six transverse rows of comb-like bristles. Costa extending well beyond the middle of the wing, about five-ninths the length of the wing; first section of costa slightly longer than the second which is about two and one-half times as long as the third (20 : 18 : 7); costal bristles rather short, delicate and set close together; cell at fork of third vein very narrow and small; fourth vein weakly curved, recurved at the base; fifth and sixth veins strongly sinuous; seventh long and practically straight. Halteres light brownish.

Type from Lalun Mts. (5,000 ft.), Davao Province, Mindanao, Philippines, July 5, 1930 (C. F. Clagg).

This species is very conspicuous on account of its large size and striking coloration. It is similar in color to the Indian *M. apicalis* Brues from which it differs by the stronger tibial bristles and shorter first costal section.

Megaselia pallidicauda sp. nov.

♂. Length 1.9 mm. Black, the abdomen beyond the second segment ochre yellow, then growing more brownish toward apex; joints and the tibiæ and tarsi of front legs yellowish, the other legs beyond the black femora brownish. Wings hyaline, with nearly black heavy veins and dark thin veins; halteres yellow. Front slightly higher than broad, with strongly raised ocellar tubercle and faintly impressed median groove; frontal bristles long and stout; four postantennal bristles of nearly equal size, the upper pair separated by one-third the width of the front, lower ones by about one-sixth its width; antial bristles set near the lower edge of the front, well away from the eye and at a level midway between the two pairs of postantennal bristles; lowest lateral bristles well above the level of the upper postantennals; upper row of four equidistant frontal bristles forming a line that curves downward slightly at the middle. Antennæ small, with long, pubescent arista; palpi distinctly compressed, with a single row of long, stout bristles below on apical half. Proboscis ovate, rounded at tip, flat below and extending slightly forward so that its apex is visible from above. Cheeks each with a pair of long downwardly directed bristles and a series of very small ones that extend upwards toward the antennæ. Mesonotum shining, quite coarsely hairy behind, with one pair of dorsocentral bristles; scutellum fully twice as wide as long, with a long bristle near each side and a much smaller one near the extreme lateral angle. Mesopleura above with a patch of minute bristly hairs. Abdomen above subopaque, the second tergite very strongly lengthened, one-half longer than the third which is also unusually large; following tergites very small. Hypopygium small, an extremely short dorsal lamella fringed with bristly hairs and a long, pale colored ventral process that extends backwards and curves upward finger-like with hairs below and short, stubby pale bristle-like erect hairs on its upper surface. Front tarsi long and slender; hind tibiæ with a single series of rather long, closely placed bristles inside the seam, near the tip internally with six or seven transverse rows of comb-like bristles. Costa extending to about the middle of the wing, with moderately long, delicate bristles. Heavy veins strongly modified; costa very thin at base, then suddenly thickened to become gradually thinner again and very thin at apex; first vein very thin; third vein slightly thicker than usual; second vein extremely short and thin, about half as long as the third section of the costa; first section of costa noticeably shorter than the second which is three times as long as the third (13 : 15 : 5). Fourth vein gently curved and broadly recurved at base, nearer than usual to the costal margin of the wing; following veins nearly straight, thin and delicate, but perfectly defined.

Type from Lalun Mountains (5,000 ft.), Davao Province, Mindanao, Philippines, July 2, 1930 (C. F. Clagg).

This species might be the male of either of the two preceding species on account of the bicolored abdomen, but as it differs from *M. conspicua* so conspicuously in frontal chætotaxy and from *M. fulvicauda* in having the third abdominal tergite yellow instead of black, I hardly think it could be either species. The wing venation is so highly modified that it is of no help in answering the question.

Megaselia brevineura sp. nov. (Fig. 11)

♂. Length 1.0 mm. Thorax piceous, head and abdomen black; antennæ brownish yellow, palpi deep yellow; pleuræ somewhat lighter than the mesonotum; legs yellowish brown; wings hyaline, with piceous veins; halteres black; lamella of hypopygium pale yellow. Front quadrate; four postantennal bristles; the upper pair larger and separated by a little more than one-fourth the width of the front and twice as far apart as those of the lower pair; antial bristles set much below and considerably nearer to the median line than the lowest lateral bristles; middle frontal row of four equidistant bristles forming a straight transverse line, rather close to the ocellar row; median frontal line well developed, the surface of the front sparsely hairy and subshining. Antennæ of normal size, with a rather stout arista. Palpi small, with very long, stout bristles at apex and on outer half below; cheeks each with three stout bristles. Mesonotum subshining, clothed with minute hairs in front and longer ones behind; one pair of dorsocentral bristles. Scutellum with two bristles. Mesopleura with a patch of small bristles, one or two of which near the lower edge of the group are somewhat longer than the others. Abdomen entirely dull black, none of the segments noticeably lengthened. Hypopygium with an oval, downwardly projecting lobe; on the left side below with one and on the right side with two, stout downwardly directed bristles. Front tarsi enlarged; first joint widened, nearly half as broad as long, more than half as long as the tibia and about two-thirds as broad; hind tibia with a single row of very delicate setulæ inside the posterior seam. Costa three-eighths the wing length, with moderately long cilia, which are however, not equal to the distance between the costa and the third vein; first section barely more than twice the length of the second section, second section nearly half longer than the third (15 : 7 : 5); fourth vein gently and evenly curved; fifth barely sinuate, nearly straight; sixth weakly sinuate; seventh straight.

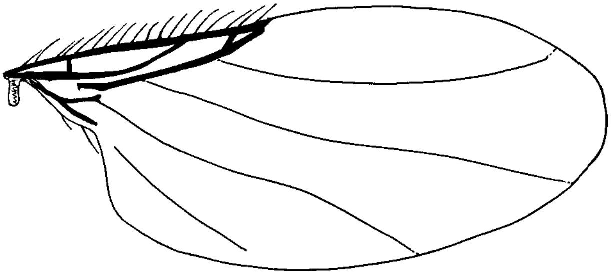

FIGURE 11. *Megaselia brevineura* sp. nov., wing.

Type and one paratype from the Galog River, 5,000 ft., Oct. 21.

Megaselia aristata sp. nov.

♂. Length 1.7 mm. Black, the posterior legs brownish beyond the femora and the front legs yellowish brown with the femora darker; palpi fuscous; wings distinctly yellowish, the venation light brown; halteres dark; hypopygial lamella pale yellow. Front quadrate, subshining and more coarsely hairy than usual; ocellar tubercle and median impressed line clearly marked; four postantennal bristles; the upper pair one-third longer than the lower, separated by nearly one-third the width of the front; lower pair separated by one-sixth the frontal width; antial bristles at a level midway between the upper and lower postantennals and well removed from the eye; lowest lateral bristles considerably above the level of the upper postantennals; upper frontal bristles forming a line that curves gently downward medially, its bristles equidistant; all frontal bristles large and strong. Antennæ small, with conspicuously pubescent arista; palpi with strong bristles below on apical half; proboscis projecting nearly to the tips of the palpi, flat below and deeply cleft medially. One large downwardly directed bristle on each cheek and a series of very delicate ones extending thence upward toward the antennæ. Mesonotum shining, with one pair of widely separated dorsocentral bristles and about six much smaller bristles between them; scutellum semicircular, with four bristles of which the lateral ones are not much smaller than the others. None of the abdominal tergites noticeably lengthened, the second apically at the sides with a group of bristly hairs; posterior edges of tergites with a series of short bristly hairs, more conspicuous on the second, fourth, and especially on the more apical segments. Hypopygium small, without conspicuous appendages below, velvety pubescent, except on lower surface which is shining. Mesopleura above with a small patch of minute bristly hairs, two or three of which are noticeably longer near the lower, hind margin of the group. Front tarsi not at all thickened. Hind tibiæ with a single series of bristles just inside the seam, these are longest just beyond the middle, where they become about as long as the width of the tibia; about five short transverse rows of comb-like bristles inwardly at the apex of the tibia. Wings long and narrow; costa four-sevenths the length of the wing, its bristles long, about equalling the distance between the costa and third vein and rather closely placed, second section of costa as long as the first and third combined and nearly four times as long as the third (14 : 19 : 5); fourth vein evenly curved, with the base strongly recurved; fifth vein nearly straight; sixth feebly sinuate; seventh long, straight.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 9, 1930 (C. F. Clagg); one paratype from the Sibulan River (7–8,000 ft.), Sept. 28 and another from the Galog River (5,000 ft.), Nov. 5.

Megaselia apoënsis sp. nov. (Fig. 12)

♂. Length 2.0 mm. Black; pleuræ piceous; hind legs very dark brown; middle tibiæ and front legs yellowish brown; palpi pale yellow; halteres brown; wings yellowish hyaline, venation dark brown; hypopygial lamella piceous, pale brown at tip. Front subshining, quadrate, with well defined ocellar tubercle and median frontal groove; four postantennal bristles, the upper ones considerably larger than the lower ones, separated by about one-fourth the width of the front; lower ones separated by one-sixth the frontal width; antial bristles close to the lowest laterals and a little below them, both set between the level of the two pairs of postantennals; upper frontal row of four equidistant bristles forming a line that curves downward slightly at the middle. Antennæ of moderate size, with thinly pubescent arista; palpi with moderately long bristles on apical half below. Cheeks each with two very long, divergent bristles below and a series of short, thin bristles extending upwards toward the antennæ. Mesonotum subshining, with one pair of very long dorsocentral bristles. Scutellum subtriangular, with one pair of long bristles and a minute one lateral to each of the large ones. Mesopleura with several small bristly hairs above along the hind margin, but in front of these the area that is usually hairy bears smaller and sometimes only the most minute, barely discernible hairs. None of the abdominal tergites elongated; sides of the abdomen with scattered short, bristly hairs which extend

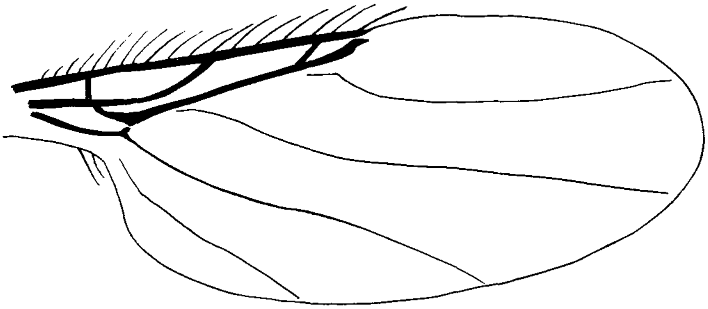

FIGURE 12. *Megaselia apoënsis* sp. nov., wing.

also across each tergite just before the hind margin, becoming longer and more conspicuous on the apical segments; sides of second segment more noticeably bristly behind. Surface of abdomen and hypopygium above dull; hypopygium globose, on the sides with a few downwardly directed stiff bristly hairs, its underside polished, bearing a small leaf-like projection in the vertical plane that extends backwards from the left side at apex. Front tarsi not noticeably thickened; hind tibiæ with a single series of bristles inside the seam; these short basally, but becoming nearly as long as the width of the tibia beyond the middle. Wings rather short and broad, but of quite even width; costa extending barely beyond the middle of the wing, with long, thin, rather closely placed bristles. First section of costa as long as the second and about two and one-half times as long as the third (13 : 13 : 5); fourth vein curved at the base and straight beyond; fifth slightly curved basally; sixth feebly sinuate; seventh long, straight.

♀. This sex is essentially similar to the male, aside from sexual differences.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 14, 1930 (C. F. Clagg). In addition there are twenty-five specimens of both sexes from the Mainit River, Galog River (5,000 ft.), Sibulan River (7–8,000 ft.), Baroring River (6,000 ft.) and from Calian, Davao Province. This is evidently a very common species.

Megaselia textilis sp. nov.

♂. Length 1.7 mm. Thorax brown, abdomen black; four anterior legs pale yellowish brown, the hind legs deeper brown; front black, antennæ fuscous, palpi deep yellow; hypopygial lamella yellowish. Wings almost hyaline, with brown venation; halteres pale brown. Front quadrate, ocellar tubercle well developed, but the median frontal line very weak; surface subshining, with sparse short hairs. Four postantennal bristles of equal size, the upper pair separated by one-third the width of the front, the lower ones by one-sixth; antial bristles set between the level of the upper and lower postantennals, well away from the eye and not far below the lowest lateral bristle; row of four equidistant preocellar bristles forming a strongly downwardly curved line; all frontal bristles large and strong. Antennæ of moderate size, with strongly pubescent arista. Palpi with moderately stout bristles apically. Cheeks each with two stout downwardly directed bristles and a series of several smaller ones extending upwards toward the antenna. Posterior edge of propleura strongly bristled above and below along posterior edge. Mesonotum subshining, with fine hairy covering; one pair of rather small dorsocentral bristles. Scutellum subtriangular, acutely rounded behind, with one pair of strong bristles and a weak hair at each lateral angle. Abdominal tergites of about equal length, the second slightly longer and without noticeable bristly hairs at the sides. Hypopygium very small, more or less globose, without evident projections, the lamella slender, cylindrical. Wings long, more narrowed apically than usual. Costa three-sevenths the wing length (32 : 77); first section nearly twice as long as the second which is nearly twice as long as the third (15 : 9 : 5). Costal bristles very long and sparsely placed; fourth vein weakly and evenly curved; fifth feebly sinuate, sixth and seventh distinctly so. Legs slender, but with the front tarsi noticeably stouter than those of the other legs; hind tibiæ with a single row of very weak setæ just inside the seam and four transverse rows of comb-like bristles internally at the tip.

Type from the Mainit River (5,500 ft.), Mt. Apo, Mindanao, Philippines.

Megaselia turbulenta sp. nov.

♂. Length 1.0 mm. Black, the mesonotum piceous and the pleuræ red-brown; legs dilute brownish yellow, the tips of the hind femora infuscated; palpi clear yellow; wings hyaline, the veins rather weak brown; halteres black. Front about as wide as high, with ocellar tubercle and well defined median impressed line, its surface more or less shining, but distinctly pollinose and with very fine, scattered hairs. Frontal bristles moderately strong; four postantennal bristles placed in a close group, the upper ones separated by about one-fourth the width of the front; antial bristles near the lower edge of the front well removed from the eye and unusually far below the lowest laterals; preocellar bristles four equidistant, forming a nearly straight transverse row more than twice as far from the postantennals as from the ocellar bristles. Antennæ and palpi small, the latter with moderately strong bristles below and near the tip. Mesonotum rather shining, strongly convex anteriorly, with comparatively strong hairs behind; one pair of weak dorsocentral bristles and two strong scutellar bristles; bristles along the lateral edges of the mesonotum strong. Mesopleura above with a patch of scattered bristly hairs and one longer, backwardly directed bristle near the lower posterior edge of the patch. Abdomen dull black, the tergites of approximately equal length; hypopygium globose, of moderate size. Front tarsi flattened and widened, the first joint half as long and nearly as wide as the tibia, following joints about twice as long as wide; hind tibiæ with a single series of weak bristles, obsolete basally and apically, inside the seam. Costa much less than one-half the length of the wing (87 : 33), its bristles moderately long and rather closely placed; first section almost twice as long as the second which is less than twice as long as the third (15 : 8 : 5); fourth vein long, very weakly curved; fifth, sixth and seventh sinuate.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines (C. F. Clagg).

This is very similar to *M. breviuscula* Brues from Formosa with which it agrees in the small size and very short costa. However, the upper postantennal bristles are much more approximate and the costal bristles shorter in the Philippine species.

Megaselia repetenda sp. nov. (Fig. 13)

♂. Length 2–2.2 mm. Thorax above rather dark brown, yellowish about the humeri and very pale brownish yellow on the pleuræ; head, including front yellow, the antennæ and palpi scarcely paler; abdomen black, the second tergite medially, all of the fifth and seventh, pale yellow; legs pale brownish yellow, the hind tibiæ black internally at apex; wings hyaline, with a brown tinge, the veins dark brown; halteres yellow, with dark stalk. Front quadrate, the ocellar tubercle and median impressed line well marked; four large, strong, equal postantennal bristles, the upper pair separated by one-half the width of the front and the lower ones by half that distance; antial bristles directly beneath the lowest lateral bristles and as close to the eye and well below the upper postantennals; lowest lateral bristle high on the front, almost as far from the antial bristle as from the lateral bristle of the preocellar row; middle pair of preocellar bristles much lower

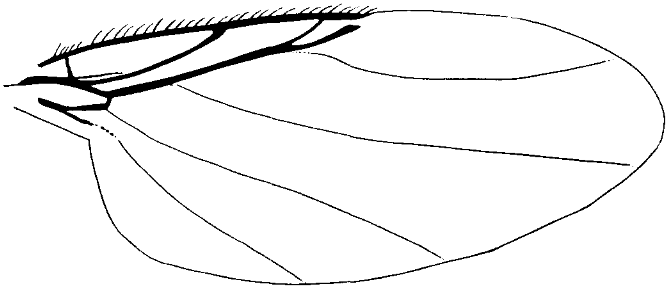

FIGURE 13. *Megaselia repetenda* sp. nov., wing.

than the lateral ones, almost as near to the level of the lowest lateral bristle as to the lateral bristle of the preocellar row. Antennæ slightly, but very distinctly enlarged, with long, densely pubescent arista; palpi of normal size, with small bristles below and several much longer ones near apex. Cheek with two very stout bristles below and a series of smaller, thinner ones extending up toward the antenna. Mesonotum not very broad, distinctly shining, densely clothed with hairs that become longer behind and are bristle like between the single pair of dorsocentral bristles. One pair of very strong scutellar bristles in addition to a smaller middle pair and a much smaller lateral one. Mesopleura entirely bare. Abdomen with opaque surface; none of the tergites noticeably lengthened; the second with a conspicuous tuft of bristles at each side. Hypopygium small; with an incurved finger-like process below at the left, fringed at tip with thin curved bristles; its lamella stout at the tip, with a pair of pointed, blade-like bristles. Legs slender, including the front tarsi; hind tibiæ with two series of bristles; one inside the seam, of bristles nearly as long as the width of the tibia, and one outside the seam, of very short bristles that do not extend to the tip of the tibia; inner surface of tibia at tip with four distinct transverse rows of comb-like bristles. Costa extending beyond the middle of the wing (95 : 55) its bristles very minute and closely placed; first section distinctly longer than the second which is nearly three times as long as the third (23 : 18 : 7); fork of third vein very acute, the second vein curved upwards to the costa; fourth vein more distinctly curved on basal half; fifth and seventh slightly arcuate; sixth feebly sinuate.

♀. Differs in having the antennæ decidedly smaller, of the usual size. As in the male, the fifth tergite is pale yellow.

Type from the Mainit River (5,500 ft.), Mt. Apo, Mindanao, Philippines, September 14, 1930; four ♂ paratypes, two of same date and locality as the type, one from the Sibulan River (7,000 ft.) Sept. 11 and the fourth from the Kidapawan Trail, Cotabato Province (7-8,000 ft.) Sept. 20. The female is from the Lalun Mountains (5,500 ft.), December 31, 1930.

All the specimens agree closely in color and exactly in the bristling of the scutellum.

Megaselia calianensis sp. nov. (Fig. 14)

♂. Length 2–2.5 mm. Thorax red brown; front somewhat blackened especially above, abdomen black, with a pale yellow, narrow apical band on tergites two to six; pleuræ light brown; antennæ dull fulvous, palpi light yellow; legs testaceous, the hind femora black at tips, wings hyaline, with faint brown tinge, veins dark; knob of halteres pale yellowish. Front quadrate, with large bristles; ocellar tubercle and median groove present; four equal, stout postantennal bristles, the upper pair separated by fully one-half the width of the front; lower pair by nearly one-third its width; antial bristles almost as near to the eye as the lowest lateral bristle, on a level with the lower postantennals; lowest lateral bristle far above the upper postantennals; median pair of bristles of preocellar row set much lower than the lateral ones, almost as far below them as above the lowest lateral bristle. Antennæ small, rounded. Palpi small, with stout bristles, especially near tips. Three very long, downwardly curved bristles on each cheek, with several shorter ones above, extending in a line toward the antenna. Mesonotum rather long, subshining, its pilosity noticeably longer behind; one pair of dorsocentral bristles. Scutellum fully twice as wide as long, with four long, equally stout, equidistant bristles along the margin. None of the abdominal tergites noticeably lengthened; surface opaque and bare except for a submarginal row of bristly hairs on each tergite (longer on the sixth) and a conspicuous tuft of bristles near each hind corner of the second tergite. Hypopygium with a finger-like projection on each side, directed obliquely downward, about the width of the lamella (anal tube) and furnished with scattered stiff hairs below and apically. Mesopleura entirely bare. Legs moderately stout, the tarsi all slender. Hind tibia with a series of rather long bristles inside the seam and a series of very small ones outside the seam, this outer row more or less obsolete on the basal and apical third of the tibia. Costa extending beyond the middle of the wing (5 : 9), with very short, closely placed bristles; first section

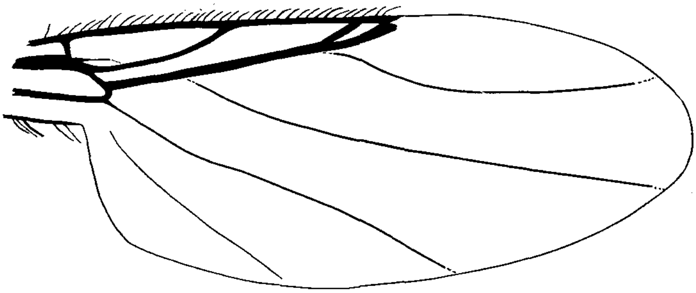

FIGURE 14. *Megaselia calianensis* sp. nov., wing.

one-third longer than the second which is about twice the length of the third (24 : 20 : 8); fourth vein curved mainly at the base; fifth, sixth and seventh nearly straight.

Type from Calian, Davao Province, Mindanao, Philippines, January 1, 1931 (C. F. Clagg); paratype ♂ from the Mainit River (5,500 ft.), September 14, 1930.

Female. Length 3–3.5 mm. Similar to the male, with the costal sections 35 : 31 : 10. Two specimens from Mt. Mayo, Davao Province (4–5,000 ft.), Jan. 30, 1931 and the Galog River (5,000 ft.), Sept. 8 (C. F. Clagg).

This species seems to be unusually variable in wing venation and on the other hand very close to the following species. After thorough examination, I think, however, that the specimens are properly segregated.

Megaselia equivocata sp. nov.

♂. Length 2.2 mm. Thorax brown, the humeri yellowish and the pleuræ reddish below; front reddish brown, darker above, antennæ dark brown; palpi saturate yellow; abdomen entirely black; legs yellow testaceous, the hind femora tipped with black; wings with yellowish brown cast, the veins dark; halteres dark brown, with black tips. Front slightly wider than long, with prominent ocellar tubercle and distinct median line, its bristles long and stout; four equal postantennal bristles, the upper pair separated by nearly half the width of the front, lower pair by one-fourth; antial bristles at the level of the lower postantennals, much farther from the eye than the lowest lateral bristle which is slightly above the upper postantennals and twice as far from the bristle above it as from the antial; middle pair of preocellar bristles set much lower than the lateral ones. Antennæ not enlarged, with long, thin arista; palpi with stout bristles; cheeks each with three long downwardly directed bristles and a series of long, thin ones extending upwards to the antenna. Mesonotum rather broad, with strong hairs behind between the dorsocentral bristles; scutellum twice as wide as long, with four bristles, the median ones much closer to one another than to the lateral ones. Abdomen with the second tergite noticeably longer than the others, with a small tuft of bristles at each side; other tergites with a marginal series of minute bristly hairs along posterior edge and some larger ones along the lateral margins. Hypopygium on each side below with a short horizontal lobe extending backwards, fringed apically with curved bristly hairs. Mesopleura entirely bare. Legs moderately stout, the hind tibiæ with two rows of bristles, one of larger ones inside the seam and a second one (incomplete basally and apically) outside the seam, composed of much shorter bristles. Costa extending slightly beyond the middle of the wing (100 : 55) with very short, closely placed bristles; first section one-half longer than the second, third less than half as long as the second (26 : 17 : 7); fourth vein curved near base, nearly straight apically; fifth, sixth and seventh nearly straight.

Type from the Sibulan River (2,000 ft.), Mt. Apo, Mindanao, Philippines, October 1, 1930 (C. F. Clagg).

This may be only a variety of the preceding species, but it seems to be clearly distinct so far as I can tell from the material at hand.

Megaselia bulbosa sp. nov.

♂. Length 3.0 mm. Yellowish brown, the pleuræ very much paler, especially below; abdomen black or very dark brown, with the posterior margins of the tergites dull yellow; legs yellow, with the tips of the hind femora black; front brownish yellow, the antennæ and palpi pale fulvous. Wings with a distinct yellowish brown cast, darker around the edges; the veins fuscous; halteres dark brown. A slender species with long wings and legs. Front fully one-fourth wider than long, its bristles strong; lower postantennal bristles minute, separated by one-fifth the width of the front, upper ones large, separated by one-third the width of the front; antial bristles well below the upper postantennals and much nearer to them than to the eye; lowest frontal bristle close to the eye and a little above the postantennals; preocellar row of four equidistant bristles, bowed downwards medially; ocelli large, the tubercle occupying one-half the width of the vertex; antennæ distinctly enlarged, the arista stout, pubescent; palpi slender, narrowed apically, with moderately stout bristles at tip. Cheek with two stout downwardly curved bristles and a series of about six slender ones extending in a line toward the antenna. Postocular cilia large. Mesonotum shining, with five unusually stout bristles along each lateral margin; one pair of dorsocentral bristles. Scutellum small, with two strong bristles and a pair of lateral bristly hairs. Mesopleura entirely bare. Abdomen long and slender, the segments of about equal length; each tergite with a subapical fringe of bristly hairs; the second with a conspicuous tuft of bristly hairs at each side. Hypopygium conspicuous, globose, with a triangular, subapical projection below. Legs long and slender; hind tibiæ with a series of widely spaced long bristles inside the seam and a second series of shorter, much more closely spaced ones outside the seam, the seam deflected toward the outside beyond the posterior third. Wings long and narrow, the costa extending two-thirds the wing length (75 : 115); costal bristles very short, closely placed; second section of costa one-third longer than the first and six times as long as the third (27 : 36 : 6); cell at fork of third vein very small, but well defined as the second vein rises sharply toward the costa. Fourth vein straight, except at base; fifth slightly bent at the middle; sixth and seventh feebly sinuate.

Type from Calian, Davao Province, Mindanao, Philippines, January 1 (C. F. Clagg).

This species is very readily recognizable by the broad front, wing venation and armature of the hind tibiæ.

Megaselia dimidiata sp. nov.

♂. Length 1.4 mm. Black; antennæ fuscous, paler below; palpi yellow; front legs, except upper side of femora brownish yellow; middle legs beyond femora, and hind tarsi yellowish brown; hypopygial lamella pale yellow; halteres black; wings slightly infuscated, the venation dark brown. Front shining, with sparse, strong hairs, slightly higher than broad, with prominent ocellar tubercle and very weak median impressed line. Only two postantennal bristles, separated by one-third the width of the front; antial bristles slightly below the lowest lateral bristles and almost touching them, the lateral bristles at the level of the postantennals; preantennal bristles equidistant, all four in a straight transverse line. Antennæ small, with a short, stout arista; palpi below and at tip with widely separated, moderately strong bristles. Mesonotum subshining, finely hairy, with one pair of dorsocentral bristles. Scutellum large, semicircular, with two long, stout bristles. Mesopleura entirely bare although its surface above is noticeably pruinose. Abdomen short and stout, dull black, bare except for sparse bristly hairs laterally and toward the tip; second segment slightly longer than the third; fifth as long as the fourth. Hypopygium bent forward under the abdomen, concealed. Front tarsi slightly, but not conspicuously thickened; hind tibiæ with two series of bristles, those inside the seam long and widely separated, those outside the seam much shorter and becoming very weak on the apical third; seam straight, not angulate apically. Costa extending just to the middle of the wing, with very short, fine bristles. First section of costa about one-third longer than the second which is more than twice as long as the third (13 : 10 : 4). Cell at fork of third vein rather narrow, as the second vein is strongly oblique; fourth vein bent at base and less strongly so apically; fifth and sixth feebly sinuous; seventh long, nearly straight.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, October 21, 1930 (C. F. Clagg).

Megaselia quadrata sp. nov.

♀. Length 2 mm. Thorax brownish yellow, the front black; antennæ, palpi and abdomen clear yellow, the latter with tergites one, three, four and five blackened except in the middle of three to five and with the extreme tip black; legs yellowish testaceous; wings hyaline, with fuscous venation; halteres black. Front quadrate, ocellar tubercle and median impressed line sharply defined; two large and two very small postantennal bristles, the former separated by a little less than one-third the width of the front; antial bristles below the lowest lateral bristles on a level with the upper postantennals and almost as near to them as to the eye; four preocellar bristles equidistant, but with the median pair decidedly lower than the lateral bristles. Each cheek with two large downwardly directed bristles and a series of seven small ones extending upwards to the antenna. Antennæ small, rounded; palpi small, with stout, widely separated bristles below. Mesonotum subshining, densely, finely hairy in front, sparsely and more coarsely so behind; one pair of rather small dorsocentral bristles; scutellum with two bristles and two bristly hairs lateral to the bristles. Mesopleura entirely bare above. Abdomen broad at base, evenly narrowed apically; all six tergites fully sclerotized, the second one-third longer than each of the following ones; surface dull, with scattered, conspicuous, black, bristly hairs on the posterior half of the second and all of the following tergites. Hind tibiæ with straight hair-seam, with two rows of bristles, those in the series external to the seam stout, nearly as long as the width of the tibia; those of the outer row much shorter and very closely placed. Wings narrow, the costa extending very slightly beyond the middle of the wing (77 : 40) costal bristles very short and closely placed; first section of costa slightly longer than the second which is three times the length of the third (17 : 15 : 5); fourth vein curved at base and apex, nearly straight near the middle; fifth faintly sinuous, sixth distinctly so; seventh straight.

Type from Todaya Plateau (4,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 2, 1930 (C. F. Clagg).

Megaselia maculipennis sp. nov. (Fig. 15)

♀. Length 2.2 mm. Head and thorax pale dull yellow, the mesonotum darkened medially and at the sides; pleuræ stained with brown below; abdomen black at base, the second tergite fulvous, tergites

3–5 pale yellow, sixth bright yellow with a small round black spot at each side behind, seventh black; legs brownish yellow, the hind femora blackened at tips; wings distinctly tinged with yellowish, the veins pale brown; a distinct brown spot filling the cell at the fork of the third vein and extending slightly beyond, above the base of the fourth vein. Front slightly wider than high; ocellar tubercle and median impressed line distinct; two strong postantennal bristles, separated by one-fourth the width of the front, and a very small lower pair; antial bristles midway between the median line and the eye, at the level of the upper postantennals; lowest lateral bristle farther from the eye than usual and well above the antial bristles; four equidistant pre-ocellar bristles forming a line that is slightly curved downwards medially. Antennæ small, rounded, with strongly pubescent arista; palpi small, with moderately strong, widely divergent bristles on apical half below; each cheek with two strong downwardly directed bristles and a series of small ones extending upwards toward the antenna. Mesonotum subshining, with two dorsocentral bristles and a rather conspicuous pair of smaller bristles between the dorsocentrals. Scutellum, twice as broad as long, with four bristles, the middle pair much stronger than the lateral one. Abdomen partly membranous at the sides, the fourth and fifth tergites much reduced in width, each scarcely wider than and somewhat shorter than the sixth; third tergite apparently entirely membranous; second tergite with very conspicuous bristles along the lateral edges; fourth and fifth with minute bristles at tip, sixth segment with a fringe of longer bristles at apex; seventh segment tubular, clothed with sparse, rather long, bristly hairs. Mesopleura entirely bare above. Hind tibiæ with a single series of bristles inside the seam, these are longest near the middle of

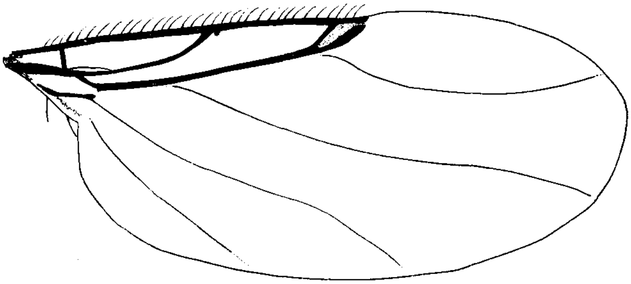

FIGURE 15. *Megaselia maculipennis* sp. nov., wing.

the tibia and nowhere as long as the width of the tibia. Costa extending well beyond the middle of the wing (49 : 85), its bristles very short and closely placed; first section distinctly longer than the second which is slightly more than three times the length of the third (19 : 17 : 5); fork of third vein acute, the cell elongate triangular; fourth vein evenly curved, except for the briefly recurved base; fifth and sixth strongly sinuate; seventh weak, feebly sinuate.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, November 5, 1930 (C. F. Clagg); paratype from Lalun Mts. (5,500 ft.), Davao Province, Mindanao, Philippines, July 3 (C. F. Clagg).

Megaselia brevisecta sp. nov. (Fig. 16)

♀. Length 2.0 mm. Thorax above light brown; front and pleuræ brownish yellow, abdomen black; legs testaceous, the tips of hind femora blackened; antennæ pale brown, darker at tips; palpi pale brown. Wings distinctly brownish, the veins fuscous; halteres black. Front quadrate, with distinct ocellar tubercle and median impressed line. Lower pair of postantennal bristles very small and slender, upper pair large and stout, separated by nearly one-third the width of the front; antial bristles near the lower margin of the front, at the level of the upper postantennals, almost as far from the eye as from the median line; preocellar row of four equidistant bristles forming a straight, transverse line at the upper third of the front. Antennæ small, with strongly pubescent arista; palpi with moderately long bristles at tips. Mesonotum elongate, its surface subshining; one pair of dorsocentral bristles; bristles along lateral margin unusually large; scutellum twice as wide as long, with two very long and two small bristles. Mesopleura entirely bare above. Abdominal tergites all of

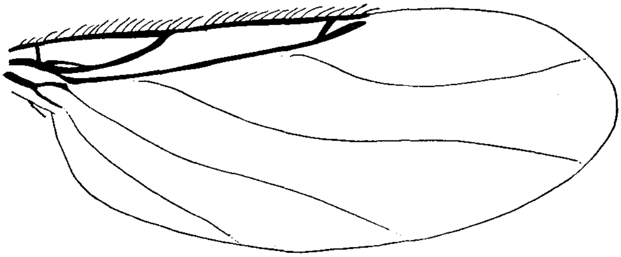

FIGURE 16. *Megaselia brevisecta* sp. nov., wing.

approximately equal length, the apical ones with noticeable scattered bristly hairs; second tergite with a conspicuous band of small bristles along the lateral margin. Legs slender, the hind tibiæ with a single row of widely spaced bristles inside the seam; these much shorter than the width of the tibia. Costa extending well beyond the middle of the wing (87 : 52), with short, very densely placed bristles; first section barely more than half as long as the second; third less than one-fourth as long as the second (12 : 23 : 5); fork of third vein not very acute, the second vein rising sharply to the costa and the cell nearly an isosceles triangle; fourth vein more strongly curved at the base; fifth and sixth strongly sinuate; seventh feebly so.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 6, 1930 (C. F. Clagg).

Megaselia lino nsis sp. nov.

♀. Length 2.4 mm. Head and thorax piceous, the humeri and sides of the mesonotum rufous; abdomen black; antennæ piceous, much paler reddish internally at base; palpi clear yellow; abdomen black; legs brownish yellow, the hind pair darker, with nearly black femora. Wings slightly brownish, with brown veins; halteres yellowish white. Front two-fifths wider than long with broad flat ocellar tubercle and distinct median impressed line; surface pollinose; four postantennal bristles, the lower pair much thinner and considerably shorter than the upper, and not much closer together; the upper ones separated by one-fifth the width of the front; antial bristles on a level with the lower postantennals, midway between the median line and the eye; lowest lateral bristles at the level of the upper postantennals and farther from the eye than usual; preocellar row of four equidistant, forming a downwardly bowed line, nearer to the postocellar row than to the postantennals; all frontal bristles large and strong. Antennæ small, with loosely pubescent arista; palpi narrow, with moderately long bristles. Mesonotum broad, shining, sparsely hairy, especially behind; one pair of long dorsocentral bristles; the bristles of the lateral margin large. Scutellum one-half broader than long, with four long, stout, equal bristles. Mesopleura entirely bare above, although the surface near the base of the wing is slightly wrinkled in an oblique direction. Abdomen stout, the tergites of approximately equal length, with a few scattered minute bristly hairs, more conspicuous laterally and at the tip of the abdomen; five fully sclerotized tergites, the sixth segment small, narrow, tubular; each side of second tergite with a linear series of about five long, conspicuous bristles. Legs rather slender in comparison to the quite stout body; hind tibiæ with a single series of bristles inside the seam, these are short near its base and apex, but attain a length equal to the width of the tibia near the middle. Costa extending well beyond the middle of the wing (102 : 62), with moderately short, rather closely placed bristles; second section of costa about one-third longer than the first and nearly five times as long as the third (22 : 29 : 6); fork of third vein very acute, the second vein much longer than the third section of the costa; fourth vein strongly curved at the base, practically straight beyond; fifth feebly curved before middle; sixth slightly sinuous; seventh long, curved, sinuous toward the tip.

♂. A much smaller specimen may be the male of this species but the second section of the costa is longer (14 : 20 : 5) and the front not quite so wide. The antennæ are conspicuously enlarged.

Type from Lino Lake (8,000 ft.), Mt. Apo, Mindanao, Philippines, September 19, 1930 (C. F. Clagg). Male from the Galog River (5,000 ft.), September 22, 1930.

Megaselia setifrons sp. nov.

♂. Length 2.2 mm. Mesonotum and front reddish brown, the ocellar region black; humeri, front margin of mesonotum, pleuræ, metanotum and base of first abdominal tergite pale yellow; abdomen otherwise black, with the posterior edge of each tergite broadly margined with yellow; antennæ light orange-yellow; palpi fulvous; legs testaceous, the hind femora blackened at tips; wings hyaline, with very dark veins; halteres black. Front quadrate, with large, elevated ocellar tubercle which occupies fully half the width of the front and deep median frontal groove; four large, equal postantennal bristles, the lower pair separated by a little less than, and the upper by a little more than one-third the width of the front; antial bristles between the level of the upper and lower postantennals, close to the eye although not so near as the lowest lateral bristles which are far above them, directed obliquely inwards; four equidistant preocellar bristles of which the middle pair is much lower than the lateral one. Surface of front glaucous or pruinose, the sparse hairs between the bristles larger than usual, especially in the region of the postantennal bristles. Antennæ noticeably enlarged, rounded, with long, thinly pubescent arista. Palpi small, with long bristles below on apical half. Cheek with two large, downwardly curved bristles which are scarcely larger than the lower ones of a gradually decreasing series that extends upward to each antenna. A large, fleshy proboscis extending between the palpi causes them to be more widely separated than is usual. Mesonotum broad and short, with one pair of very widely separated dorsocentral bristles; scutellum fully twice as wide as long, with four strong marginal bristles. Mesopleura entirely bare above. Abdomen broad at base, but rapidly narrowed behind the second segment, its surface semi-opaque, clothed with sparse bristly hairs that are longest on each tergite just before the yellow apical band; second tergite longest, but not noticeably elongated, without trace of lateral bristles. Hypopygium nearly symmetrical, large, pear-shaped when seen from above; its lamella yellow, clothed with bristly hairs; seen from the side the hypopygium is triangularly produced at the lower corner behind to form a blunt tooth; this and the posterior edge are clothed with thin curved bristles. Legs slender, hind tibiæ with a single series of bristles inside the seam, these increasing evenly in length from the base of the tibia, but never attaining a length equal to the tibial width. Wings broad at the middle, obtusely narrowed apically; costa extending well beyond the middle of the wing (85 : 50), its bristles short and closely placed, first section of costa about one-third longer than the second which is twice as long as the third (23 : 17 : 8); third vein slightly, but very distinctly widened along its middle third; fork of third vein very acute; costa extending for a noticeable distance beyond the tip of the third vein; mediastinal vein entirely lacking when the wing is viewed from above, weakly indicated when seen obliquely from the front; fourth vein curved at base, straight beyond; fifth straight; sixth and seventh feebly sinuate.

Type from the Sibulan River (7–8,000 ft.), Mt. Apo, Mindanao, Philippines, September 21, 1930 (C. F. Clagg).

The obsolescence of the mediastinal vein is nearly complete, but the species does not otherwise agree with related genera that lack this vein and I have therefore placed it in Megaselia.

Megaselia tubulata sp. nov.

♀. Length 2.1 mm., including the tubular ovipositor. Brownish yellow, the abdomen black and the front black, except below and on the lower portion of the sides; antennæ and palpi pale orange-yellow; legs pale yellow; wings hyaline with brownish tinge, the veins brown; halteres pale. Front about one and one-half times as broad as high, with broad ocellar tubercle and deeply impressed median line; four postantennal bristles, but the lower pair minute, very much smaller than the upper ones which are close together, separated by scarcely one-sixth the width of the front; antial bristles level with, or slightly below the lower postantennals, slightly nearer to the eye than to the upper postantennals; lowest lateral bristles but little above the antials, further from them than from the eye; pro-ocellars equidistant, forming a slightly arcuate line; all bristles large and stout. Antennæ oval, distinctly larger than is usual; palpi of normal size, with stout bristles below toward tips; four long downwardly directed bristles at the lower corner of the eye and two small ones above, nearer to the antenna. Mesonotum rather broad, subshining, its pubescence very fine, except behind; one pair of dorsocentral bristles placed very wide apart; scutellum broad, fully twice as wide as long, with four large and equal bristles. Mesopleura entirely without hairs or bristles above. Abdomen broad at the base and evenly narrowed to the sixth tergite; none of the tergites noticeably elongated; second with a tuft of small bristles at each side; ovipositor extruded for a distance equal to the length of the second and third tergites together; it is considerably depressed, with flat upper surface and apparently composed of two segments of which the basal is three times as long as the apical one; the width of the base is fully twice that of the apex and equal to one-third the total length; the extreme tip is somewhat swollen and bears some very minute bristly hairs. Legs rather slender; hind tibiæ with a single row of short, fine, closely placed bristles inside the seam. Costa extending almost to the middle of the wing, with short, widely separated bristles; first section of costa nearly twice as long as the second; third less than half as long as the second (18 : 10 : 4); second section of costa noticeably bowed outward along the wing margin and the third vein beyond the fork similarly bowed, toward the base of the fourth vein; second vein also curving upwards to meet the costa; fourth vein evenly curved; fifth, sixth and seventh feebly sinuate.

♂. Length 1.6 mm. Differs from the female in having the antennæ greatly enlarged, the third joint oval and slightly larger than the eye; arista short and very finely pubescent. To accommodate the greatly enlarged antennal cavities the front is greatly shortened, the costal sections are of noticeably different proportions, the second only half the length of the first and the third five-eighths the length of the second (16 : 8 : 5).

Type from Lawa, Davao Province, Mindanao, Philippines, May 4, 1930. Male from the Galog River (5,000 ft.), October 22, 1930; both specimens collected by C. F. Clagg.

Although the male differs considerably in wing venation, it agrees so closely in many characters that I feel quite positive that it is conspecific.

Megaselia montana sp. nov.

♀. Length 2.1 mm. Black, the mesonotum stained with reddish brown at the posterior corners; pleuræ piceous below; front legs, including coxæ testaceous, middle and hind legs successively darker, the tips of the hind femora blackened; antennæ brown at base; palpi dark saturate yellow; halteres pale yellowish. Wings hyaline, veins dark brown. Front slightly wider than long, with well marked ocellar tubercle and median frontal groove; surface of front strongly pollinose and very sparsely clothed with minute bristly hairs; four postantennal bristles, the lower pair very small and the upper one smaller than the other frontal bristles; upper pair separated by about one-fifth the width of the front; antial bristles lower than the upper postantennals and about midway between the eye and the median line; lowest lateral bristles level with the upper postantennals; four equidistant proocellar bristles forming a nearly straight line, the median pair but little lower than the lateral one. Two strong downwardly directed bristles on each cheek and a series of very short ones above extending toward the antenna. Antennæ small, rounded, with long, thinly pubescent arista; palpi stout, with moderately long, closely placed bristles. Mesonotum subshining, with one pair of widely separated dorsocentral bristles. Scutellum twice as wide as long, with four equally large, strong bristles. Abdomen pollinose above, with scattered, small bristly hairs, none of the tergites noticeably lengthened nor shortened; second tergite with a patch of small bristles at each side; six tergites completely formed. Mesopleura entirely bare above. Legs rather stout; hair seam of hind tibia distinctly, evenly arcuate, a single series of bristles inside the seam, these widely spaced and strong on the posterior third of the tibia where they are nearly as long as the width of the tibia. Costa long, extending to slightly beyond the middle of the wing, its cilia long and rather widely spaced; first section of costa one-half longer than the second which is a little more than twice as long as the third; fork of third vein acute, the third vein curved toward the costa at the tip so that the cell is very short above.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 9, 1930 (C. F. Clagg).

Megaselia translocata sp. nov.

♀. Length 1.5 mm. Black, the pleuræ piceous; front and middle legs fuscous, hind legs piceous; palpi pale brown; halteres pale; wings slightly, but distinctly infuscated, the veins dark brown. Front shining, less hairy than usual, distinctly wider than long (about 11 : 9), with long bristles, small ocellar tubercle and median frontal line well developed; four postantennal bristles, the lower pair about half the size of the upper which are separated by one-fourth the width of the front; antial bristles midway between the eye and the upper postantennals, set on a level with the lower postantennals; lowest lateral bristle slightly higher than the antial, further from the eye than usual; median pair of preocellar bristles nearer to one another than to the lateral bristles and set at a lower level, midway between the upper postantennal and ocellar bristles. Antennæ small, with long, densely pubescent arista. Palpi with moderately strong bristles. Mesonotum shining, elongate and very strongly convex, with unusually large bristles on the lateral margins; one pair of dorsocentral bristles; scutellum subtriangular, its base narrower than usual, with one pair of large bristles. Mesopleura entirely bare. Legs long and quite stout, but with the hind femora not at all widened; front tarsi stout, but not really thickened nor enlarged; hind tibiæ with the hair seam gently arcuate, one series of short, fine bristles outside the seam, these very weak at base and apex; inside of hind tibia with three transverse rows of comb-like bristles at apex. Abdomen subshining, all of the tergites fully sclerotized; surface clothed with sparse, minute, bristly hairs; sides of second tergite with a very inconspicuous group of small bristles. Wings long and ample, rather narrow; costal bristles moderately long, very closely placed. Costa extending somewhat beyond the middle of the wing (80 : 45), distinctly widened near the middle where it is about twice as thick as usual; very thin near the humeral cross-vein, thence widened to the tip of the first vein, thence imperceptibly reduced to its normal thickness at apex; second vein very thin, others normal; second vein rising very sharply to the costa; fourth vein moderately and evenly arcuate; fifth and sixth feebly sinuate; seventh straight.

Type from the Mainit River (5,500 ft.), Mt. Apo, Mindanao, Philippines, September 14, 1930 (C. F. Clagg).

In this species the costa is very clearly, but not grossly, thickened and distinctly sinuous, with its first section curved posteriorly and its second one curved anteriorly.

Megaselia mediata sp. nov. (Fig. 17)

♀. Length 1.7 mm. Head and thorax yellow, the lower part of pleuræ, antennæ and palpi decidedly paler; ocellar tubercle black; legs testaceous, with the tips of hind femora blackened, abdomen black, the base of the second tergite and all of the sixth yellowish; halteres black. Front quadrate, barely wider than high, the surface pollinose, clothed with sparse minute bristly hairs, its bristles very strong; ocellar tubercle and median frontal line well developed; four postantennal bristles, the lower pair much weaker than the upper which are separated by one-third the width of the front; antial close to the lower margin of the front, near to and just below the lowest lateral bristle which is level with the upper postantennals, middle pair of preocellar bristles nearer to one another than to the lateral pair and set considerably below them, somewhat nearer to the upper postantennals than to the ocellar bristles. Antennæ rather large, with long, densely pubescent arista; palpi with stout bristles below at apex; cheek with two strong downwardly directed bristles and a close set series of small, slender ones above, extending toward the antenna. Mesonotum long and narrow, strongly convex, subshining; its pubescence fine, even behind; one pair of small dorsocentral bristles. Scutellum with one pair of strong bristles, in addition to a bristly hair at each side. Mesopleura entirely bare. Abdomen with all the tergites fully sclerotized, tapering apically; surface opaque, clothed with very delicate, scattered, bristly hairs, more conspicuous near apex; second tergite slightly lengthened, one-third longer than the third, with a few weak bristles at each side. Legs slender, but with the front tarsi stouter than usual, the second and third joints each about twice as long as thick. Costa extending beyond the middle of the wing (77 : 42), its cilia extremely short and closely placed; first section distinctly shorter than the second which is three times as long as the third (15 : 18 : 6); the costa is thicker than usual from near base to apex, about twice the thickness of the third vein; fourth vein more strongly curved at base and apex; fifth considerably curved before middle; sixth and seventh feebly sinuate.

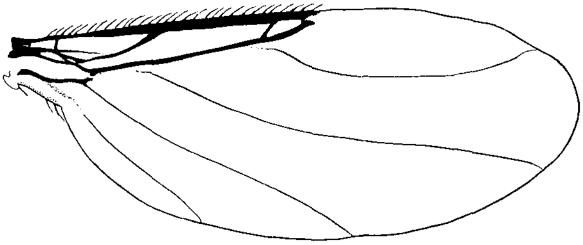

FIGURE 17. *Megaselia mediata* sp. nov., wing.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, October 22, 1930 (C. F. Clagg).

Megaselia mutata sp. nov.

♀. Length 1.8 mm. Brownish yellow, upper half of front blackish and abdomen piceous with the hind margins of tergites two to four whitish; pleuræ and legs pale yellow, the tips of the hind femora blackened. Wings hyaline, veins very dark; halteres dark. Front quadrate, sparsely and rather coarsely hairy; ocellar tubercle and median impressed line well developed. Four postantennal bristles, the upper pair much stronger than the lower ones, separated by scarcely one-fourth the width of the front; antial bristles at the level of the upper postantennals, not much below, but much farther from the eye than the lowest lateral bristles; preocellar row of four equidistant bristles forming a gently downwardly curved line. Antennæ small, with long, thinly pubescent arista; palpi with very stout bristles on apical half below. Mesonotum elongate and narrow, its surface hairs much stronger behind; one pair of dorsocentral bristles; scutellum with one pair of long bristles and a lateral bristly hair at each side. Mesopleura entirely bare. Abdomen slender, shining, none of the tergites noticeably lengthened except the sixth, which is much narrower and about twice as long as the fifth; surface almost devoid of bristly hairs except along the lateral posterior margins of the tergites. Front tarsi moderately slender; hind tibiæ with a single series of weak bristles, obsolete basally, outside the seam. Costa extending about to the middle of the wing, very strongly arcuate with the anterior edge concave; in addition to this curvature, it is humped upward before the second vein, thus greatly deforming the form of the costal wing margin; costa thin on the basal sixth, then rapidly swollen to near middle, then gradually reduced to its normal thickness at apex; first vein very thin, entering the costa just beyond its basal third; second vein normal; third vein noticeably thickened and strongly bowed in parallel manner with the costa; fourth vein curved only near base; fifth also curved on basal half; sixth and seventh nearly straight.

Type from Calian, Davao Province, Mindanao, Philippines, January 1, 1931 (C. F. Clagg).

The form of the wing is very unusual, especially the bending of the costa in two different planes, and I suspect that the species may not be able to fly. Were it not that the two wings are exactly symmetrical one might think the twisting an individual abnormality and of course it may be such, possibly similar to certain mutations of the kind observed in Drosophila. Even so, the specimen cannot be identical with either of the two more or less similar forms described on the following pages.

Megaselia bihamulata sp. nov. (Fig. 18)

♀. Length 2.0 mm. Brownish yellow, the abdomen fuscous beyond the second segment; the sides of the mesonotum in front, antennæ, palpi and legs paler yellow; tips of hind femora blackened; ocellar tubercle black. Wings with a slight yellowish cast, the veins light brown; halteres very dark brown. Front quadrate, with well developed ocellar tubercle and deep median impressed line, the bristles very large and stout; surface subshining, with sparse, short, bristly hairs; four postantennal bristles, the lower pair thinner, but not much shorter than the upper ones which are separated by nearly one-third the width of the front; antial bristles set almost as high on the front as the lowest lateral bristles and very close to the latter which are next to the eye-margin; preocellar bristles equidistant forming a line that is bowed down medially, the middle pair midway between the ocellar tubercle and the postantennal bristles. Antennæ small, with densely pubescent arista; palpi with weak bristles below, becoming much stronger at apex. Two very strong bristles on the cheek and a close set series of small slender ones extending up toward the antenna. Mesonotum shining, highly convex anteriorly, with one pair of rather strong dorsocentral bristles. Scutellum with two strong bristles and two minute lateral bristles. Mesopleura entirely bare. Abdomen with six complete tergites of full width and also a seventh narrow one which projects beyond the sixth; at each side of the posterior edge of the seventh there extends upwards and forwards a thin, evenly curved spine-like process, about as long as the width of the tibia; beyond this

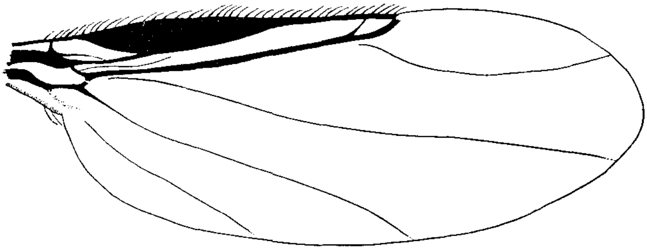

FIGURE 18. *Megaselia bihamulata* sp. nov., wing.

is the usual fleshy tip and minute cerci. Front tarsi slightly thicker than usual; hind tibia with a single series of sparsely placed bristles outside the seam, the bristles considerably shorter than the width of the tibia. Wings long and narrow, the costa extending considerably beyond the middle of the wing; first section one-third as long as the second and twice as long as the third (10 : 30 : 5), its bristles very short and closely placed; costa greatly swollen from near the base to somewhat beyond the middle, its anterior margin straight, but the inner edge quite evenly bowed, the thickening ending quite suddenly near the apical third; first vein very thin; second and third normal; fourth vein slightly and evenly curved, fifth to seventh each feebly sinuate.

Type from the Mainit River (5,500 ft.), Mt. Apo, Mindanao, Philippines, September 14, 1930 (C. F. Clagg). Paratype from the Mainit River (5,000 ft.), November 5 (C. F. Clagg).

This species resembles the preceding and also the following species, but differs from each clearly as set forth in the key. These several forms are similar to some closely related European species (*e.g.*, *M. crassicosta* Strobl, *M. brunneipennis* Costa), but all differ slightly in wing venation and none so far as I know show any peculiar genital armature.

Megaselia appendiculata sp. nov. (Fig. 19)

♀. Length 1.7–2.0 mm. Thorax brownish yellow; head, including antennæ and palpi paler; abdomen subshining, piceous, with the base of the second tergite yellowish; legs testaceous, with the hind femora tipped with black; wings with yellowish tinge, the veins dark, but with the swollen part of the costa much paler; halteres black. Front and its bristles as in the preceding species, also the antennæ and palpi. Mesonotum narrow, with one pair of slender dorsocentral macrochætæ; scutellum with two very strong bristles and two lateral bristly

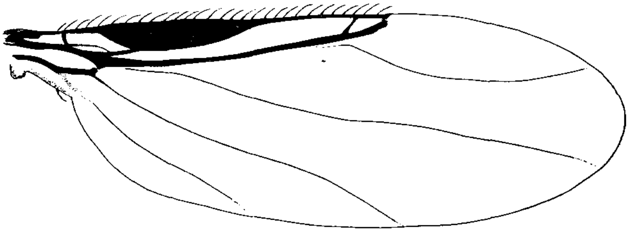

FIGURE 19. *Megaselia appendiculata* sp. nov., wing.

hairs; mesopleura entirely bare. Abdomen as in the preceding species, except at apex. Seventh tergite triangular, pollinose, with a sharp, polished median ridge that extends backward as a small downwardly curved spine; lateral processes at the sides of the seventh tergite bending upwards and forwards, but sharply angulate at the middle and obliquely truncate at tip. Wings essentially as in the preceding species, but differing slightly as indicated in the accompanying figure.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, November 5, 1930 (C. F. Clagg). Four paratypes, three of same date and locality as the type and one from Calian, Davao Province January 1, 1931.

This species and the two foregoing are undoubtedly very similar and closely related. However, considering the entirely consistent differences in the seventh tergite and its appendages they are readily separable, although previous to a very minute examination I had placed them together. Still more unexpected is the fact that two of the forms were taken at Calian on the same date and likewise two on the Mainit River on the same date.

Megaselia directa sp. nov.

♀. Length 1.5 mm. Pale brownish yellow; abdomen piceous, except the second tergite and membranous part of the sixth; front blackened above; ocellar tubercle black; antennæ and palpi very pale; wings hyaline, with light brown veins; halteres black; legs pale testaceous, the hind femora tipped with black. Front quadrate, barely wider than high, with strong bristles. Ocellar tubercle and median impressed line present. Four postantennal bristles, the upper pair much stronger than the lower, separated by about one-fourth the width of the front; lower ones by half that distance; antial bristles directed strongly inwards, inserted at the lower margin of the front, near to and only slightly lower than the lowest lateral bristle which is very close to the eye; four equidistant preocellar bristles forming a gently down-curved line. Antennæ small, with densely pubescent arista; cheeks each with two moderately strong downwardly directed bristles and a close series of very delicate ones extending upwards toward the antenna; palpi slender, with strong bristles below and at tip. Mesonotum narrow, shining, its pubescence noticeably bristly behind; one pair of dorsocentral bristles; scutellum with two bristles and a bristly hair lateral to each bristle. Abdomen with five complete tergites, the second somewhat longer than the others and with a few very small bristles at each side; sixth tergite minute, appearing only as an elongate-oval appendage at the center of the posterior edge of the fifth, although the membranous part of the sixth segment is nearly as wide as and longer than the fifth. Mesopleura entirely bare. Legs slender; the front tarsi, however, slightly thicker than usual; hind tibiæ with a series of delicate bristles outside the seam, these very short basally and two-thirds as long as the width of the tibiæ on the apical half of the row. Wings long and narrow, the venation much modified; costa extending beyond the middle of the wing (64 : 37), its bristles closely placed and very minute, especially near base and apex; first section of costa only about one-fourth as long as the second (9 : 34), third section not indicated as the second vein is absent; costa thickened immediately beyond the first vein to about three times its normal width, then imperceptibly thinner to apex which is of the usual thickness; third vein approaching closely to the costa just beyond the tip of the first vein and extending thence practically in contact with the costa to tip; mediastinal vein visible as a ridge, but not clearly pigmented; fourth vein curved only at base; following veins faintly sinuate, the seventh very delicate.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, October 22, 1930 (C. F. Clagg).

The peculiar venation of this species is characteristic, with the parallel and closely approximate costa and third vein. The absence of the second vein is to be expected under such conditions as there is really no gap to be bridged and I can detect no indication of any thickening or closer contact near the place it should be indicated.

Megaselia incompleta sp. nov. (Fig. 20)

♂. Length 1.3 mm. Black, the four posterior legs piceous; palpi, base of antennæ and legs brownish yellow; anal tube pale yellow; wings hyaline; heavy veins black, light veins rather weak. Front slightly, but distinctly higher than broad; ocellar tubercle narrow; median frontal groove very sharply impressed; surface pollinose, with very sparse hairs; four postantennal bristles, the lower pair greatly reduced, half the size of the upper ones which are separated by almost one-third the width of the front; antial bristles set at the level of the upper postantennals, directed obliquely inwards and almost as near to the eye as the lowest lateral bristles which are inserted much higher on the front than the antials; preocellar bristles equidistant, forming a straight transverse line, twice as far from the postantennals as from the ocellar bristles. Antennæ small, with densely pubescent arista; palpi with weak bristles below and several stronger ones at tip. Cheeks each with two moderately long bristles below and a series of minute ones extending upwards toward the antenna. Mesonotum shining, rather broad; finely pubescent, the portion behind the base of the wings bristly; one pair of small dorsocentral bristles; two scutellar bristles, no lateral scutellar hairs. Mesopleura entirely bare. Abdomen opaque, bare on basal part, with very minute scattered hairs apically and a marginal fringe of bristly hairs on the sixth tergite; second tergite noticeably lengthened, one-half longer than the others. Legs stout for such a slender species, the front tarsi rather slender; hind tibiæ with a rather strong fringe of bristles inside the seam, the longest ones about three-fourths as long as the width of the tibia.

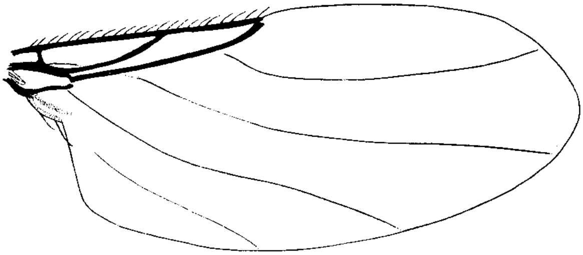

FIGURE 20. *Megaselia incompleta* sp. nov., wing.

Costa not extending to the middle of the wing (49 : 21), its bristles extremely short, closely placed. Second vein entirely absent, not indicated by the slightest trace; first section of costa as long as the second (21 : 20); fourth vein nearly straight, only weakly curved toward the base; fifth and sixth faintly sinuate; seventh barely visible.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, October 23, 1930 (C. F. Clagg). Two paratypes, one from the same locality, October 22 and the other from the Galog River (5,000 ft.), October 8, collected in "trap lantern."

This species is placed in Megaselia, as an aberrant species lacking the fork of the third vein like a very few other members of the genus. It might perhaps be referred to the closely similar *Veruanus* Schmitz known by a single species from Europe. The mediastinal vein is very weakly indicated, but this does not seem to be entirely reliable as a generic character.

Megaselia politifrons sp. nov. (Fig. 21)

♀. Length 1.4–1.5 mm. Shining black, the surface polished, especially on the front and apical portion of abdomen; lower half of pleuræ, coxæ, all of four anterior legs, except front tarsi, and palpi yellowish testaceous; hind legs black or piceous, the base of the femora paler and the basal third of the tibiæ testaceous. Wings slightly infuscated, with very dark venation; halteres white. Front slightly higher than broad; ocellar tubercle small; median impressed line poorly defined below and absent above; upper half of front smooth and polished, lower half sparsely hairy, the hairs set in minute, conspicuous punctures; four postantennal bristles, the lower pair much reduced in size, the upper pair separated by almost one-third the width of the front; antial bristles set very close to and scarcely below the lowest lateral bristles at the lower corner of the front; four equidistant preocellar bristles forming a gently downwardly curved line, the middle pair midway between the ocellars and upper postantennals. Antennæ small, with thinly pubescent arista; palpi rather broad, with moderately strong bristles. Mesonotum with one pair of unusually small dorsocentral bristles and several bristles almost as large between them. Scutellum with two rather small bristles and a lateral hair near each bristle. Pleuræ shining, the mesopleura shagreened above, but without hairs or bristles. Front tarsi rather stout. Hind tibiæ much constricted at base, of normal thickness from just before the middle, at which point the hair-seam is deflected outwards; a single series of moderately strong bristles inside the seam on the apical half, wanting basally. Abdomen slender, the tergites of approximately equal length. Wings elongate, quite narrow, the costa extending slightly beyond the middle, its bristles moderately short and rather closely placed; first section of costa slightly longer than the second which is twice as long

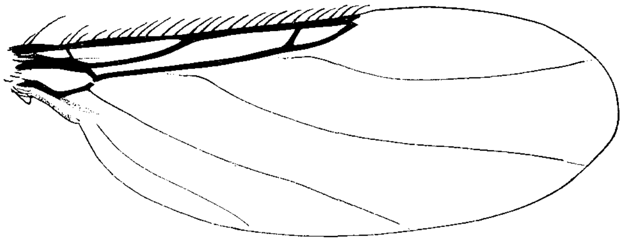

FIGURE 21. *Megaselia politifrons* sp. nov., wing.

as the third (13 : 12 : 6); fourth vein weakly curved, fifth and sixth weakly sinuate; seventh as strong as the preceding.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 6, 1930 (C. F. Clagg); two paratypes, one from Bakrayan, 7,000 ft., September 14, and the second from the Galog River (5,000 ft.), September 8.

This species is conspicuous on account of the shining black body, resembling the widely distributed holarctic *M. minor* Zett. in this and many other characters, but differing by the small lower postantennal bristles, partially impunctate front and configuration of the hind tibiæ. A single male is similar, but with the halteres and entire pleuræ black.

Megaselia bisecta sp. nov.

♀. Length 1.4–1.7 mm. Dull brownish yellow, darker on the middle of the mesonotum and paler on the antennæ, palpi, humeri, sides of mesonotum and scutellum; abdomen blackish on apical parts of three tergites, with the base of the second tergite conspicuously pale; wings hyaline with yellowish tinge, the venation light brown; halteres pale brownish. Front quadrate, with strongly developed ocellar tubercle and well impressed median line, its bristles very long and stout; four postantennal bristles, the lower pair greatly reduced in size, upper pair separated by a little less than one-third the width of the front; antial bristles below the level of the upper postantennals, slightly lower than and twice as far from the eye as the lowest lateral bristles; preocellar bristles equidistant, forming a nearly straight transverse line, the middle pair much nearer to the postantennal than to the ocellar bristles. Antennæ noticeably larger than usual, with strongly pubescent arista; palpi with strong bristles below toward tips; cheeks each with two very stout bristles below and a close-set series of shorter slender ones extending upwards toward the antenna. Mesonotum rather shining, with very fine, dense pubescence; one pair of dorsocentral bristles; scutellum with two very strong bristles, the lateral bristle-like hairs practically obsolete. Mesopleura entirely bare. Abdomen with the tergites of approximately equal length; bare above, but with fine hair-like bristles along the sides, stronger on the second tergite. Legs slender, the front tarsi not at all thickened; hind tibiæ with the hair-seam curving outward beyond the middle; a single series of rather weak bristles inside the seam on the apical half of the tibia, obsolete on basal half. Costa extending to the middle of the wing, its bristles short and closely placed; first section nearly one and one-half times as long as the second; third very short, little more than one-third the length of the second (16 : 11 : 4); fourth vein very weakly curved; fifth and sixth slightly sinuate; seventh more or less obsolete basally.

Type from La Lun Mts., Davao Province, Mindanao, Philippines (C. F. Clagg); three paratypes, two from Calian, January 1 and one from the Mainit River (5,000 ft.), Sept. 9 (C. F. Clagg).

Megaselia unisetosa sp. nov. (Fig. 22)

♂. Length 1.6–1.8 mm. Black, the palpi dusky yellow and the legs brownish apically; wings slightly infuscated, the veins black; halteres pale brownish. Front slightly wider than high, strongly pollinose; very sparingly hairy, practically bare above; its bristles large and strong; ocellar tubercle small, the median impressed line showing as a fine, polished line; four postantennal bristles, the lower pair considerably reduced in size, about half as long as the upper ones which are separated by about one-fourth the width of the front; antial bristles set almost as low on the front as the lower postantennals, not far below the lowest lateral bristles, but much farther from the eye; preocellar row of four equidistant bristles, the median pair scarcely below the level of the lateral ones and slightly nearer to the ocellars than to the upper postantennals. Antennæ small, with short, thinly pubescent arista; palpi heavily bristled on apical half below; cheeks each with four long bristles below and a series of shorter, thin ones extending upwards to the antenna. Mesonotum short and broad, its pubescence bristly behind, between the single pair of long dorsocentral bristles. Scutellum narrow, sharply rounded apically, with two long stout bristles; mesopleura entirely bare, its surface above obliquely roughened. Abdomen subshining above, with bristly hairs along the sides of the tergites, especially the second; fifth tergite with

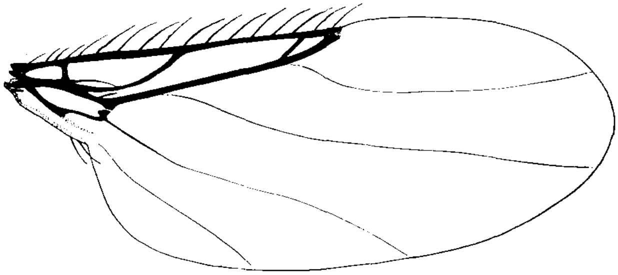

FIGURE 22. *Megaselia unisetosa* sp. nov., wing.

a submarginal series of short, bristly hairs, sixth with a series of six much longer ones. Hypopygium small, simple, its dorsal lamella with scattered, rather large bristly hairs. Legs stout, the front tarsi rather thick, but not really enlarged, hind tibiæ with the dorsal hair-seam strongly arcuate on basal third; one series of widely spaced bristles, nearly as long as the width of the tibia, inside the seam. Costa extending beyond the middle of the wing (55 : 35), its bristles very long and widely spaced; first section of costa a trifle shorter than the second which is nearly three times as long as the third (10 : 11 : 4); third vein with a single, quite strong bristle at base; fork of third vein acute; fourth vein weakly curved; fifth and sixth feebly sinuate, seventh nearly straight.

Type from the Mainit River (5,500 ft.), Mt. Apo, Mindanao, Philippines, September 14, 1930 (C. F. Clagg). Four paratypes, three from the same locality on the same date and one from the Galog River (5,000 ft.), September 22, 1930.

The stout bristle at the base of the third vein is an unusual character. The species is similar to the European *M. tarsella* Lundbeck and several related species, differing however in the short first section of the costa and tibial bristles. From the Formosan *M. pedicellata* Brues it differs in frontal chætotaxy.

Megaselia vapidicornis sp. nov. (Fig. 23)

♀. Length 1.6–1.8 mm. Dull ochre yellow, somewhat brighter with a fulvous cast on the abdomen; front black, the palpi and antennæ, especially the latter very pale yellow; abdomen with the fourth tergite piceous and the ovipositor black; front legs very pale, hind femora tipped with black; wings hyaline, with rather pale brown venation; halteres black. Front about as wide as high, its surface pollinose, scarcely shining, with very fine sparse hairs, the bristles strong; ocellar tubercle and median frontal line sharply defined. Four postantennal bristles, the lower pair very small, less than half the size of the upper ones which are separated by about one-fourth the width of the front; antial bristles at the level of the upper postantennals, slightly below the lowest lateral bristles and much farther from the eye; preocellar row of four equidistant bristles forming a slightly downwardly curved line, the median ones midway between the ocellar and upper postantennal bristles. Cheek with two strong bristles, directed downwards and a series of unusually small ones extending upwards toward the antenna. Antennæ rather large, conspicuous by their unusually pale color, the arista black, thinly pubescent; palpi with a heavy fringe of bristles below. Mesonotum rather narrow, very strongly convex, its pubescence gradually sparser and coarser posteriorly; one pair of small dorsocentral bristles; scutellum subtriangular, with one pair of strong bristles and a bristly hair at each side. Mesopleura entirely bare and smooth above. Surface of abdomen dull, with very sparsely scattered minute hairs, longer apically; second tergite with a few bristles at each side behind; the third and fourth with similar minute bristles; six sclerotized tergites, the second longest and the sixth greatly narrowed. Ovipositor about as long as the second tergite and nearly half as high as long, compressed somewhat and narrowed apically in dorsal view; its surface irregularly longitudinally aciculate, clothed with sparse short hairs; no visible appendages at the apex. Legs slender, the front tarsi rather slender; hind tibiæ with a moderately strong series of bristles inside the seam. Wings rather narrow basally, the costa extending slightly beyond the middle of the wing, its bristles very short and closely placed; first section shorter than the second which is nearly four times as long as the third (13 : 15 : 4); cell at fork of third vein very small; fourth vein evenly and not strongly curved; fifth and sixth feebly sinuate; seventh long.

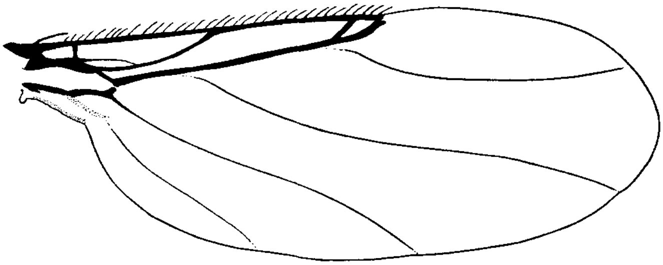

FIGURE 23. *Megaselia rapidicornis* sp. nov., wing.

Type from the Lalun Mountains, Davao Province, Mindanao, Philippines (5,500 ft.), December 31, 1930 (C. F. Clagg). Four paratypes; two from the Lalun Mts., July 2 and 3, and two from Calian, Jan. 1 and July 23.

Megaselia equisecta sp. nov. (Fig. 24)

♀. Length 2.3 mm. Thorax brownish yellow; abdomen black; front dull yellow, infuscated above; antennæ reddish brown, black at tips; palpi yellow; legs yellowish brown, the tips of the hind femora broadly blackened. Wings tinged with brown, the veins dark brown; halteres black. Front distinctly broader than high, with extremely long bristles; ocellar tubercle small, strongly raised; median impressed line distinct. Surface of front rather shining, with closely placed black hairs. Four postantennal bristles, the lower pair very small, the upper ones separated by one-fourth the width of the front; antial bristles at the lower margin of the front, nearly as far from the eye as from the median line and a little below the postantennals; lowest lateral bristle well above the antial, not so close to the eye as usual; four preocellar bristles equidistant, the middle pair scarcely lower on the front than the lateral ones and nearer to the ocellar bristles than to the postantennals. Antennæ small, with closely pubescent arista; palpi small, with strong bristles. Cheek with two very strong downwardly directed bristles and a series of short, delicate ones extending upward to the antenna. Thorax stout, the mesonotum broad, its pubescence conspicuously bristly behind; one pair of dorsocentral bristles; scutellum transverse, semicircular, with two very long bristles, the lateral hair very minute. Mesopleura entirely bare. Abdomen stout, gradually attenuated, all of the tergites fully sclerotized, the sixth much narrowed, but fully covering the dorsal surface of the segment; second tergite with a few rather long bristles at each side behind and the margins of the tergites with minute bristly hairs along their posterior margins, not larger nor more conspicuous on the apical segments. Front tarsi slender; hind tibiæ with a series of strong bristles, two-thirds as long as the width of the tibia, inside the seam. Costa extending barely beyond the middle of the wing (95 : 53), its bristles moderately long, closely placed; first section about as long as the second and three times as long as the third (21 : 20 : 7); fork of third vein very

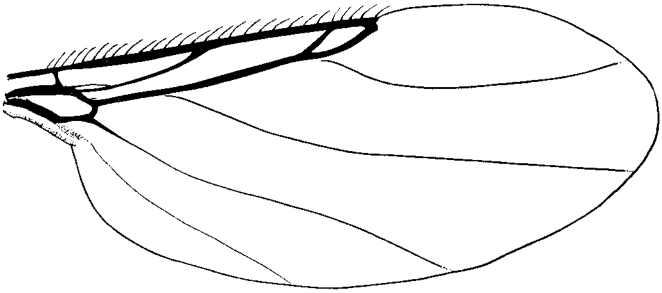

FIGURE 24. *Megaselia equisecta* sp. nov., wing.

acute, the last section of the third vein much longer than the third section of the costa, the second vein rising gently to the costa; fourth vein weakly curved at base, nearly straight beyond; fifth feebly curved; sixth feebly sinuate; seventh straight.

Type from the Sibulan River (7,000 ft.), Mt. Apo, Mindanao, Philippines, September 11 (C. F. Clagg). Paratype from the Galog River (5,000 ft.), Sept. 22.

Megaselia clavipedella sp. nov.

♂. Length 1.0 mm. Shining black; antennæ dark fuscous; palpi yellow; front legs pale yellow; four posterior legs piceous with the middle trochanters and tibiæ pale yellow; wings slightly brownish along the light veins, venation brown. Halteres black. Front slightly higher than wide; ocellar tubercle and median frontal groove completely absent; surface highly polished, destitute of all except the most minute hairs, with scattered, very shallow punctures. Four postantennal bristles, the lower pair noticeably smaller and very close together; upper ones very much above the lower ones and separated by one-half the width of the front; antial bristles much below the lowest laterals, not very far from the eye, the lowest laterals much higher on the front than usual; median pair of preocellar bristles set much lower than the lateral bristles. Antennæ small; palpi with stout bristles. Mesonotum polished, with fine, short, silken pubescence which becomes more bristly behind; one pair of dorsocentral bristles. Scutellum large, subtriangular, with rounded apex, with two large bristles. Mesopleura without hairs or bristles above. Abdomen dull above, shining on the apical third, bare, except for sparse, minute bristles on the sides apically. Front tarsi considerably swollen, the first joint half as long and more than half as thick as the tibia, the following joints about half longer than thick; hind tibiæ with a single series of rather weak bristles inside the seam. Wings with the costa extending almost to the middle, its bristles moderately long, closely placed; first section of costa about the length of the second which is more than twice the length of the third (7.5 : 7 : 3); fourth vein very weakly curved, more noticeably so near the base.

Type from the Lalun Mts., Davao Province, Mindanao, Philippines July 2, 1930 (C. F. Clagg). Paratype from the Galog River (5,500 ft.), Mt. Apo, Sept. 14.

This is an extremely small species, resembling in its shining head and thorax *M. politifrons* described on a previous page. It differs so greatly, however, in venation and frontal chætotaxy as well as in size, that it certainly is not the opposite sex of that species.

Megaselia barbata sp. nov.

♀. Length 1.9 mm. Thorax deep brownish yellow above, the pleuræ darker above and lighter below; front black, its lower margin paler; antennæ piceous, palpi dark yellow; abdomen piceous, the surface strongly shining; legs uniformly pale brownish yellow; wings slightly brownish, the venation dark brown; halteres black. Front fully one-half wider than high, its surface shining, with elevated ocellar tubercle and very deeply impressed median line, the minute hairs very sparse and weak, the bristles rather short. Four postantennal bristles, the lower pair slightly reduced in size, but not much smaller than the upper which are separated by scarcely more than one-sixth the width of the front; antial bristles below the level of the upper postantennals, slightly farther from them than from the eye, distinctly below the lowest lateral bristles which are close to the eye; preocellar bristles equidistant from one another, the median pair only slightly lower than the lateral ones, placed midway between the upper postantennals and the ocellar bristles. Antennæ moderately large, with long arista; palpi with long, but rather slender bristles. Cheek with three or four long downwardly directed bristles that gradually pass into a short slender series that extends upward toward the antenna. Mesonotum short and broad, shining, its pubescence slightly bristly behind; one pair of delicate dorsocentral bristles; scutellum subtriangular, acutely rounded behind, with two long, slender bristles and a very minute bristly hair at each lateral angle. All abdominal tergites fully sclerotized, the surface bare, except for weak lateral and marginal bristly hairs on the first four tergites; fifth tergite large, semicircularly rounded at apex, with a fringe of rather long bristles on the middle part of the hind margin; sixth tergite very small, more weakly bristled. Mesopleura entirely bare. Front tarsi very slender; hind tibiæ rather stout, but with a series of extremely short bristles inside the seam; although so short, these bristles are stout, not hairlike. Costa extending slightly beyond the middle of the wing, its bristles moderately long and closely placed; first section of costa as long as the two others together; second nearly twice as long as the third (39 : 25 : 15); space between costa and third vein unusually broad; fourth vein more strongly curved at base; fifth strongly sinuate; sixth less so; seventh nearly straight.

Type from the Lalun Mts. (5,500 ft.), Davao Province, Mindanao, Philippines, Jan. 3, 1931 (C. F. Clagg).

This species may possibly be the female of *M. extensifrons* sp. nov. which it resembles especially in the wide front. However, the frontal chætotaxy is different and the first section of the costa much longer, quite as long as the other two together.

Megaselia digressa sp. nov. (Fig. 25)

♀. Length 1.7 mm. Head and thorax brownish yellow, the pleuræ paler below and the front slightly infuscated above, the antennæ lighter yellow; abdomen black, the second tergite and the base of the fifth fulvous yellow; legs testaceous, the hind femora blackened apically; wings pale brownish, the veins light brown; halteres black. Front very slightly wider than high, its surface subshining, with unusually sparse and scattered minute black hairs; ocellar tubercle broad, the median impressed line weakly indicated; four postantennal bristles, the upper pair separated by fully half the width of the front, the lower ones by one-fourth the width of the front; antial bristles very close to the lowest lateral bristles and not much below the level of the lateral ones, a little nearer to the upper postantennals than to the ocellar bristles. Antennæ small, arista strongly pubescent; palpi with stout, closely set bristles below on apical half; cheek with two strong bristles below and minute ones above extending in a line toward the antenna. Pubescence of mesonotum bristly behind; one pair of moderately strong dorsocentral bristles. Scutellum with acutely rounded apical margin; two long bristles and a lateral minute one at each side. Mesopleura entirely bare. Abdomen dull basally, more shining on the apical part, weakly bristly along the sides, but without conspicuous tufts at the sides of the second tergite; six fully sclerotized tergites, the second slightly elongated and the fifth strongly so; sixth narrow, but covering the upper side of the segment. Legs, including the front tarsi, slender; hind tibiæ with a single row of bristles inside the seam, these very minute at base, becoming as long as half the width of the

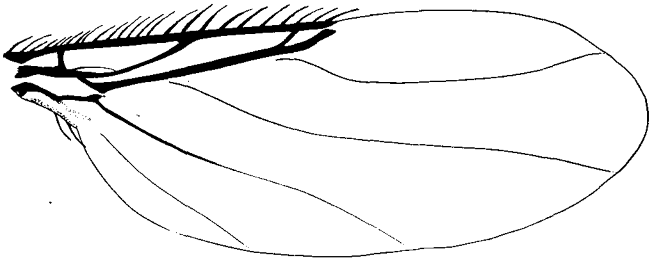

FIGURE 25. *Megaselia digressa* sp. nov., wing.

tibia apically. Wings rather elongate, the costa extending to the middle (70 : 35), its bristles long, especially near the middle and rather widely spaced; first and second sections equal, the third more than one-third as long (13 : 13 : 5); fourth vein weakly curved; fifth and sixth sinuate; seventh nearly straight, weak basally.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, September 10, 1930 (C. F. Clagg). Four paratypes, two from the same place, Sept. 10 and Sept. 24; two from the Galog River (5,000 ft.), November 5.

Megaselia extensifrons sp. nov.

♂. Length 1.7 mm. Brownish or yellow, with black abdomen; front, antennæ and palpi brownish yellow, the antennæ darker below and the front above; mesonotum with a distinct dark stripe occupying the median third, except in front; abdomen yellow at extreme base and with the tergites all margined with yellow behind; hypopygial lamella pale yellow; pleuræ and legs very pale yellow, the hind femora dusky at tips; wings weakly brownish, the veins dark and the discal ones margined with dark streaks; halteres black. Front very wide, slightly more than twice as broad as high, with conspicuous scattered black hairs; surface quite shining, but not polished, the bristles strong. Four large, equal postantennal bristles, the upper pair occupying about one-fourth the width of the front, at the same level as the antials and lowest lateral bristles; antials twice as far from the median line as from the eye; preocellar bristles forming a line that is weakly curved downwards medially. Antennæ slightly enlarged, with long, thinly pubescent arista. Palpi with unusually stout bristles below at tips. Cheek with two stout bristles, but the series that extends toward the antenna is feeble. Mesonotum broad, its pubescence moderately bristly behind; one pair of strong dorsocentral bristles. Scutellum wide and short, with evenly arcuate margin, with two very strong bristles, and a bristly hair at each lateral corner. Abdomen short and stout, the tergites short and of approximately equal length, with very small bristly hairs laterally and along the posterior margins of the tergites, stronger on the sixth tergite which bears also small discal bristles; sides of second tergite with a tuft of moderate bristles. Hypopygium rounded, pollinose, its lamella broadly compressed, with two conspicuous curved bristles at tip. Mesopleura entirely bare. Legs rather stout; the front tarsi slender; hind tibiæ with a series of rather strong bristles inside the seam, longest on the posterior half where they are nearly as long as the width of the tibia. Costa extending barely beyond the middle of the wing (76 : 40), its bristles short and closely placed; first section decidedly longer than the second and three times as long as the third (18 : 15 : 5); the costa and third vein unusually stout, although not swollen or enlarged; fork of third vein very acute, the second vein longer than the third section of the costa; fourth vein evenly curved, recurved at extreme base; fifth feebly curved; sixth and seventh slightly sinuate, the seventh longer than usual.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, November 5, 1930 (C. F. Clagg).

This species is well marked among the Philippine species by the form and chætotaxy of the front. It is in many characters very much like the palæarctic *M. glabrifrons* Wood. As noted under the description of *M. barbata* on a previous page, it resembles that species.

Megaselia apposita sp. nov.

♀. Length 2.0 mm. Thorax yellowish brown; front lighter, the antennæ and palpi pale yellow; abdomen black, more or less suffused with yellow on the median basal portions of the tergites; legs yellowish or pale brownish, the front pair much lighter; wings slightly yellowish, with deep brown venation; halteres black. Front shining slightly wider than long, with very few scattered hairs, its bristles long; ocellar tubercle and median impressed line well marked; four postantennal bristles, the lower pair much reduced in size, about half the size of the upper ones; antial bristles below the level of the upper postantennals, nearly twice as far from them as from the eye, considerably below and much farther from the eye than the lowest lateral bristles; four equidistant preocellar bristles, the median pair a little lower than the lateral ones and about midway between the median ocellus and the upper postantennal bristles. Cheek with two strong downwardly directed bristles and several slender widely separated ones extending in a series toward the antenna; antennæ of moderate size, apparently more oval than usual, the arista with very short pubescence; palpi with short stout bristles apically. Mesonotum moderately broad, shining, with very long stout lateral bristles, its pubescence bristly behind; one pair of dorsocentral bristles; scutellum with one pair of very long bristles and a minute bristly hair at each side. Mesopleura entirely bare. Abdomen stout, with all the tergites fully sclerotized; second tergite with a tuft of noticeable bristles at each side; dorsal surface otherwise scarcely bristly or hairy except on the sixth segment and beyond; extreme tip quite heavily sclerotized above, with sparse long bristly hairs. Tarsi slender; hind tibiæ with a single series of very small bristles, obsolete apically, inside the seam. Wings elongate, ample; costa extending well beyond the middle of the wing (87 : 50), its bristles very short and densely placed; first section of costa as long as the second and third together, third about one-third the length of the second (23 : 17 : 6); fork of third vein not very acute, the second vein scarcely as long as the third section of the costa; fourth vein evenly curved; fifth and sixth feebly sinuate; seventh long, barely curved.

Type from Calian, Davao Province, Mindanao, Philippines, January 1, 1931 (C. F. Clagg). Another female from the Lalun Mts., July 5, 1930 is probably the same and perhaps also one from the Mainit River (5,000 ft.), Nov. 5, 1930, but in the last the front is noticeably hairy.

Megaselia reversa sp. nov. (Fig. 26)

♀. Length 2.0 mm. Thorax and legs brownish yellow, the pleuræ and legs lighter, especially the front pair; abdomen black, with the second and sixth tergites pale yellow; front brown, lighter below and blackened above; antennæ and palpi clear yellow; hind femora broadly black at tip. Wings faintly yellowish, the veins light brown; halteres black. Front quadrate, with prominent ocellar tubercle, the median impressed line faint, especially below; surface subshining, pollinose; bristles strong; four postantennal bristles, the lower pair much reduced in size, the upper ones separated by about one-third the width of the front; antial bristles between the level of the upper and lower postantennals, close to the lowest lateral bristles which are slightly above and lateral to the antials; preocellar bristles forming a nearly straight, transverse line, with the median pair but little below the level of the lateral bristles. Antennæ small, the arista with very

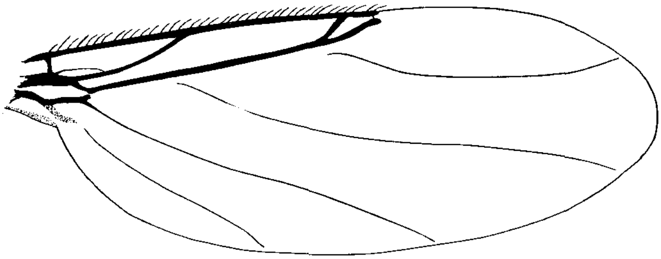

FIGURE 26. *Megaselia reversa* sp. nov., wing.

short pubescence; palpi with moderately strong bristles; cheek with two very large bristles and a series of very closely placed short, thin ones extending upward toward the antenna. Mesonotum narrow, subshining, its pubescence coarse behind, especially between the dorsocentral bristles. One pair of rather weak dorsocentral bristles. Scutellum rather broad, with sharply rounded margin, bearing two long bristles and a pair of bristly hairs. Mesopleura entirely bare. Abdomen with dull surface; six completely sclerotized tergites, none of them noticeably lengthened; surface very sparsely beset with minute bristles, the lateral margins with stronger bristles, especially on the second tergite; sixth tergite very narrow. Legs slender, including the front tarsi; hind tibiæ with a single series of bristles inside the seam, longest near the middle where they attain a length equal to three-fourths the width of the tibia; hair-seam straight, not angulate at the middle. Wings elongate; the costa, long, extending well beyond the middle of the wing (79 : 47), its bristles very short and closely placed; first section of costa less than three-fourths the length of the second which is nearly five times as long as the third (20 : 28 : 6); costa and third vein rather thin and unusually straight; cell at fork of third vein small, the second vein about the length of the third costal section; fourth vein evenly and gently curved; fifth and sixth feebly sinuate; seventh long, practically straight.

Male. Similar, with the front tarsi simple as in the female.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, September 8, 1930 (C. F. Clagg). Six paratypes: Galog River (5,000 ft.), Sept. 8, 12; two from Teo Ridge (5,500 ft.), Sept.; Mainit River (5,500 ft.), Oct. 30; Sibulan River (3,000 ft.), Nov. 11 (C. F. Clagg). There are also numerous specimens from the Sibulan, Mainit and Galog Rivers, Teo Ridge and Lalun Mountains, in which the excessive length of the second section of the costa is much reduced. These approach *M. meijerei* Brues from Java and Formosa in this respect and in the coloration of the abdomen, and may perhaps be a form of that species. However, I feel certain that *M. meijerei* and the Philippine species described above are distinct. The Formosan *M. chipensis* is also similar, but lacks the characteristic pale bands on the abdomen and the second costal section is shorter.

Megaselia patellipes sp. nov.

♂. Length 1.4 mm. Thorax pale yellowish brown, the pleuræ lighter and the legs much paler, with the hind femora black at apex; front black, brownish at the lower corners; abdomen black, the second and sixth tergites deep yellow; hypopygial lamella pale yellow; wings hyaline, the venation very dark brown; halteres black; antennæ and palpi orange yellow. Front quadrate, four postantennal bristles, the lower pair very small, the upper pair separated by about one-fourth the width of the front; antial bristles close to and slightly below the lowest lateral bristles, twice as far from the upper postantennals as from the eye; lowest lateral bristles barely above the level of the upper postantennals; median pair of preocellar bristles set considerably lower than the lateral ones, nearer to the postantennals than to the ocellar bristles. Antennæ small, rounded, with long, strongly pubescent arista; palpi with about three strong apical bristles, the more basal ones much weaker. Cheek with two moderately long bristles below and some very small ones extending in a series toward the antenna. Mesonotum narrow, strongly convex anteriorly, its pubescence bristly behind; one pair of small dorsocentral macrochætæ. Scutellum subtriangular, with two long, rather approximate bristles and a minute lateral bristly hair at each side. Mesopleura entirely bare. Abdomen small, much narrowed beyond the second segment, its surface dull; none of the tergites noticeably lengthened; sides of second tergite with a few thin, rather long bristles; lateral margins of the other tergites with scattered bristly hairs which become longer and extend over the dorsal surface of tergites five and six. Hypopygium large, pyriform, bent vertically downwards, its median lamella long, clavate, with fine, short, curled, bristly hairs apically. Legs slender, the front tarsi curiously modified and flattened. The first joint is about half as long as the tibia, slightly widened from base to apex where it is nearly as broad as the tibia, its undersurface clothed with a brush of stiff oblique hairs; second joint reniform, considerably wider, with its apical edge oblique; third and fourth similar to, but smaller than the second; fifth minute, with the claws well developed. Hind tibia with the hair-seam not noticeably angulate; one series of very weak, fine bristles inside the seam, obsolete basally. Costa extending well beyond the middle of the wing (74 : 45), its bristles short, densely placed; first section as long as the second which is about three times as long as the third (27 : 28 : 10); fourth vein weakly curved, especially at the middle; fifth curved basally, gently recurved beyond middle; sixth gently sinuate; seventh long, nearly straight.

Type from the Lalun Mts. (5,500 ft.), Davao Province, Mindanao, Philippines, May 3, 1930 (C. F. Clagg).

This species is colored very similarly to *M. reversa* sp. nov., but the second section of the costa is not elongated as in that species, and the postantennal bristles are much approximated. The male differs in the striking modification of the front tarsi which are simple in the male of *reversa*.

Megaselia deflexa sp. nov.

♀. Length 2.6 mm. Thorax brownish yellow; abdomen black with yellowish stains basally on the first, second and fifth tergites, the sixth segment yellow; legs very pale yellowish, the hind femora blackened apically; front black, brownish on anterior border, antennæ light brown; palpi pale yellow; wings weakly brownish, the veins light brown; halteres black. Front quadrate or very slightly wider than high, its surface subshining, slightly pollinose, rather densely hairy, the hairs bristly below. Four postantennal bristles, the lower pair considerably reduced in size, but more than half as long as the upper which are separated by about one-fourth the width of the front; antial bristles very close to the lowest laterals, just inside and below them; middle pair of preocellar bristles much lower than the lateral ones, slightly nearer to the upper proclinate bristles than to the anterior ocellus; ocellar tubercle strongly convex, the median impressed line distinct. Antennæ small, with long, thinly pubescent arista; palpi with very strong bristles below and at tip; cheek with two large bristles and a close set series of slender ones extending upward to the antenna. Mesonotum rather broad, very strongly bristled at the sides behind; one pair of rather small dorsocentral bristles; scutellum rather long, its margin acutely rounded, with two long, strong bristles and a small lateral bristly hair at each side. Abdomen large, tapering, with six sclerotized tergites, although the sixth is very narrow; sides with a few weak bristles, except on the second tergite which bears a group of very much larger ones. Mesopleura entirely bare. Legs strong, the tarsi slender; hind tibiæ with the posterior hair-seam angulate at the middle, thence deflected externally so that its apical half lies farther to the side and away from the single row of bristles that extends along the inside of the seam, the bristles stout, but short, especially at the base. Wings long, rather narrow; the costa extending to well beyond the middle (100 : 58), its bristles very short and closely placed; second section fully one-third longer than the first and four times as long as the third (19 : 26 : 6); fork of third vein acute; fourth vein curved more strongly near the base; following three veins all clearly sinuate.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, October 21, 1930 (C. F. Clagg).

This species is very similar to *M. reversa* sp. nov., but is much larger and the hair-seam on the hind tibia is strongly deflected outwards beyond the middle.

Megaselia inflaticornis sp. nov.

♂. Length 1.5 mm. Thorax brownish yellow; legs considerably paler; abdomen black, the first and basal half of second tergite yellow and a median stripe on the second to fifth tergites deep yellow; front black, yellowish brown below; antennæ black with the base light brown; palpi pale yellow; halteres black; wings faintly infuscated, with very dark veins. Front quadrate, the ocellar tubercle strongly elevated, the median frontal line feebly impressed; bristles very large and stout; only two postantennal bristles, set close together, occupying only about one-seventh the width of the front; antial bristles set considerably below the postantennals, as far from the eyes as from one another; lowest lateral bristles not quite so close to the eye as usual, about one-third as far from the eye as from the antials; preocellar bristles set unusually high on the front, the median pair lower than the lateral ones and fully twice as far from the postantennals as from the median ocellus. Antennæ oval, sharply rounded at tips, the third joint fully three-fourths as long as the width of the front; arista shorter than usual, sparsely pubescent; palpi narrow, with weakly developed bristles. Cheek with two unusually stout, downwardly directed bristles. Mesonotum coarsely pubescent, quite bristly behind, its lateral bristles very strong; one pair of moderately large dorsocentral bristles. Scutellum nearly semicircular, with two large bristles and a very small lateral bristle at each side. Mesopleura entirely bare. Legs rather stout, the first four joints of the front tarsus swollen, the basal joint nearly as thick as the tibia and four-sevenths as long; hind tibia with a single series of short, stout bristles inside the seam, much shorter at base and apex, near the middle three-fourths as long as the width of the tibia. Abdomen broad at base, evenly narrowed behind, its surface more or less pollinose; minutely bristly beyond the second tergite and quite strongly so on the sixth; second tergite much elongated, as long as the two following together, its lateral margins with a series of rather long bristles. Hypopygium globular, rather large; its lamella short, much compressed, with conspicuous, thin black hairs on the sides, the apical pair of bristles small. Costa extending distinctly beyond the middle of the wing (70 : 45), its bristles very short and closely placed; first section slightly shorter than the second; third one-third as long as the first (31 : 36 : 10); fork of third vein very acute; fourth vein weakly curved, faintly recurved at base; sixth and seventh feebly sinuate; seventh slightly curved.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 10, 1930 (C. F. Clagg).

This species is readily to be distinguished by the unusual chætotaxy of the front, enlarged tarsi, swollen antennæ and peculiar hypopygial lamella.

Megaselia teoënsis sp. nov.

♀. Length 2.4 mm. Thorax pale brownish yellow, much lighter on the sides of the mesothorax behind the wings and on the pleuræ; abdomen black; tergites two and six entirely and the posterior edges, except sides, of three and four light yellow; front light brown, darker medially, the ocellar tubercle black; antennæ and palpi light yellow; legs pale brownish yellow, the hind femora tipped with black; wings very slightly yellowish, the veins brown; halteres black. Front about one-fifth broader than high, its surface rather shining, sparsely and finely hairy, with strong bristles; four postantennal bristles, the lower pair distinctly, but not greatly reduced in size and not much closer together than the upper pair which occupies one-fourth the width of the front; antials very close to the lowest lateral bristles at the lower corners of the front, below the level of the upper postantennals; four preocellar bristles forming a slightly downwardly curved line, the median pair as much approximated as the upper postantennals and much nearer to one another than to the lateral bristles, midway between the median ocellus and the postantennals. Antennæ small, with long, closely pubescent arista; palpi narrow, with strong bristles apically; cheek with two strong downwardly curved bristles and a series of long very thin ones extending upwards along the eye. Pubescence of mesonotum fine anteriorly, slightly bristly behind, one pair of well developed dorsocentral bristles; scutellum sharply rounded behind, with two long bristles and a lateral minute bristly hair at each side. Mesopleura entirely bare above. Abdomen large, gradually tapering, the tergites of approximately equal length, all fully sclerotized, including the large sixth tergite; surface subshining, practically bare except for minute bristles along the sides and a more conspicuous tuft of larger bristles at the sides of the second tergite. Legs rather stout, the front tarsi noticeably stout and shortened; hind tibiæ with straight hair-seam and a single row of bristles inside the seam, these bristles stout, but all distinctly shorter than the width of the tibia. Costa extending to slightly beyond the middle of the wing (100 : 53), its bristles minute and densely placed; first section barely shorter than the second and four times as long as the third (19 : 21 : 5); fork of third vein acute, forming a small, narrow cell;

fourth vein curved at base, practically straight beyond; fifth gently curved, sixth and seventh scarcely sinuate, the seventh long.

Type from Teo Ridge (6,500 ft.), Mt. Apo, Mindanao, Philippines, September, 1930 (C. F. Clagg).

This species is very similar to *M. reversa* sp. nov., but differs clearly in the characters brought forth in the preceding key.

Megaselia perumbrata sp. nov. (Fig. 27)

♀. Length 1.8 mm. Black, the humeri and extreme lateral margin of mesonotum brownish yellow; antennæ light brown; palpi yellow; pleuræ piceous, brown in front; legs pale yellowish, the apical third of the hind femora and basal third of hind tibiæ blackened. Wings subhyaline, with a slight brown tinge; veins brown. Front quadrate, its surface subshining, clothed with very sparse, minute hairs, the bristles stout; four postantennal bristles, the lower pair greatly reduced in size, upper pair separated by one-fourth the width of the front; antial bristles close to the lowest lateral bristles, below them and below the level of the upper postantennals; middle pair of preocellar bristles set much lower than the lateral ones, a little nearer to the median ocellus than to the postantennal bristles. Antennæ small, with long, closely pubescent arista. Palpi narrow, with moderately large bristles. Cheek with two large bristles below and a series of close-set, long, thin, smaller bristles extending toward the antenna. Mesonotum moderately broad, subshining, with silken pubescence which becomes bristly at the extreme posterior part where there are several well developed bristles between the dorsocentrals which are smaller than usual. Scutellum with two long marginal bristles and a minute lateral bristly hair at each side. Mesopleura entirely bare. Abdomen dull black, gradually tapering; all of the tergites fully

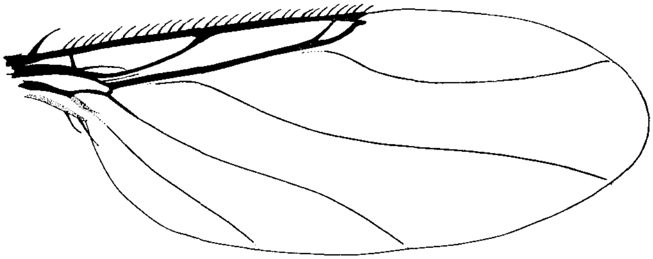

FIGURE 27. *Megaselia perumbrata* sp. nov., wing.

sclerotized, none of them noticeably elongated; sides of abdomen bearing scattered short bristles, noticeably longer and stouter on the second tergite. Legs rather slender; front tarsi not noticeably thickened; hind tibiæ with the hair-seam more sharply arcuate near the middle, but not actually angulate, with one series of moderately strong bristles inside the seam. Costa extending well beyond the middle of the wing, its bristles short and closely placed; first section a little shorter than the second which is four times as long as the third (17 : 20 : 5); fourth vein weakly curved, recurved at the base; fifth curved on the basal half; sixth faintly sinuate; seventh gently curved.

♂. Somewhat smaller, but entirely similar.

Type from the Galog River (5,000 ft.), Mt. Apo, Mindanao, Philippines, Sept. 8, 1930 (C. F. Clagg). Five paratypes, two from the same place, Sept. 8 and 28; one from the Mainit River, Sept. 9; one from Todaya Plateau (5,000 ft.), Sept. 2, and one from Lawa, Davao Province, May 4, 1930.

PHALACROTOPHORA Enderlein

There are three species of this genus in the present collection, both of which are undescribed. Schmitz has recently (Tijdschr. v. Entom., vol. 75, Suppl., p. 117, 1932) recognized three subgenera, all of which are represented in the Indomalayan Region. As there has been some doubt as to the proper subgeneric location of two species which I described from Java and Formosa, I have appended a key to the Indomalayan species.

Key to Malayan Species of Phalacrotophora

Abdomen of female with six completely chitinized tergites.......1
Abdomen with only three or four chitinized tergites in the female.2
1. Mesopleura bare and antennæ small in both sexes (Subg. *Omapanta*)..3
Mesopleura clothed with bristly hairs above..*irregularis* sp. nov.
2. Four well developed tergites in the female; mesopleura bare and antennæ more or less enlarged in both sexes (Subg. *Omatessara*)..5
Only three chitinized tergites in the female; mesopleura hairy above, usually also with a large bristle (Subg. *Phalacrotophora*)..6
3. Front and mesonotum entirely black; halteres white (Java)...... *jacobsoni* Brues.
Front and mesonotum, at least anteriorly, reddish; halteres dark..4

4. Second section of costa less than half as long as the first; cell formed by the fork of the third vein of moderate size, the third section of the costa nearly half as long as the second. (Philippines). . *scutata* sp. nov.

Second section of costa four-fifths as long as the first; cell formed by the fork of the third vein extremely small, the third section of the costa only about one-fourth as long as the second...... *pallidicornis* sp. nov.

5. Wings uniformly yellowish; first section of costa much less than twice as long as the second and third together (Formosa)..... *quadrimaculata* Schmitz

Wings apically with a brownish-black band between the costal margin and the fourth vein; first section of costa about twice as long as the second and third together (Sumatra).......... *vittipennis* Schmitz

6. Front one-half higher than wide; second abdominal tergite without lateral black markings; abdomen with some orange or reddish color..7

Front narrower; second tergite with a black spot at each side; ground color of abdomen yellowish, without reddish or orange (Formosa)............................*punctifrons* Brues[1]

7. First section of costa about as long as the second and third combined; upper proclinate bristles separated by less than one-third the width of the front (Sumatra)..*oudemansi* Schmitz

First section of costa decidedly longer than the second and third combined; upper proclinate bristles separated by one-third the width of the front (Sumatra)......*auranticolor* Schmitz

Phalacrotophora (Omapanta) **scutata** sp. nov. (Fig. 28)

♀. Length 3.6–3.8 mm. Front reddish-brown; thorax yellowish brown; antennæ reddish yellow; palpi and legs pale yellowish; abdomen black with some paler markings; wings hyaline, with strong, dark brown venation; halteres black, with a pale stalk. Front wider than usual, three-fifths as wide as high near the bottom and noticeably widened above so that the width at the ocelli is three-fourths the height. Two large postantennal bristles separated by one-fourth the width of the front and nearly as large as the antial bristles which are set at the level of the postantennals and somewhat closer to them than to the eye margin; the two bristles of the lower row frontal set very close to the eye margin; four bristles of præocellar row with the median pair dividing the width of the front into equal thirds, the lateral pair close to the eye and one-third the width of the front below the lateral ones; postocellar bristles also large. Surface of front shining, but not polished, with a few very shallow setigerous punctures. Antennæ and palpi small, the latter with short bristles. Postocular cilia stout; cheek with one stout bristle and a series of about eight smaller ones extending toward the antennæ. Mesonotum shining, clothed with fine hairs; dorsocentral bristles very much stronger than a series of small bristles that lie between them; scutellum with four nearly equal bristles. Abdomen with six tergites, a seventh which forms a long flattened extension and a minute eighth at apex; first six tergites mainly with more or less extensive pale yellow markings as follows: anterior, especially the median part of the first tergite; anterior half or less, widened medially of the second, more or less distinct similar mark that does not extend to the sides on the third; second to fifth tergites with narrow marginal pale border behind, widened at the sides of second to fourth; sixth with a pale membranous triangle at each side behind, seventh and eighth pale brown. Second and sixth tergites lengthened; fifth very narrow at the middle; sixth polished, shield shaped, its base broad, rounded, the sides sharply narrowed behind, the posterior margin broadly produced triangularly at the middle; seventh tergite more than half as long as the remainder of the abdomen, twice as long as wide, with two grooves that separate a raised median part from reflexed lateral margins; eighth very small, triangular, with minute cerci projecting beyond its tip. Mesopleura bare. Front tibiæ with a single series of short, but stout bristly hairs; middle and hind tibiæ with two rows of bristles, one on each side of the dorsal seam, those on the hind tibia including 10–12 bristles in each series, these at the middle of the tibia about as long as its width;

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[1] This and the following two species are very similar and I am by no means satisfied that they are entitled to specific rank.

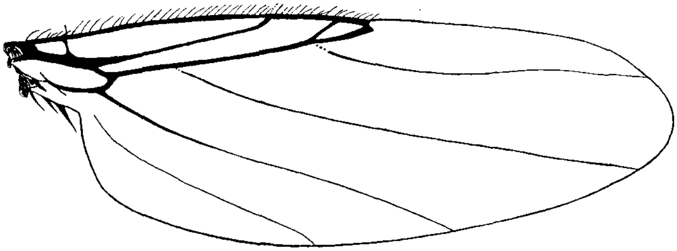

FIGURE 28. *Phalacrotophora scutata* sp. nov., wing.

wings very long and narrow, almost three times as long as broad; costa reaching to the middle, with very short cilia, first section of costa twice as long as the second and third together; the third half as long as the second; cell at fork of third vein moderately small, the fork acute; fourth vein nearly straight, faintly bisinuate; fifth, sixth and seventh strong, nearly straight.

Male. Length 2.1 mm. Similar, but with the lateral scutellar bristles decidedly weaker than the median ones; first four abdominal tergites black, with pale apical bands, except on the first; fifth tergite pale, except for the basal angles; sixth black with apical half pale; hypopygium small, rounded, shining black, its lamella long, rust red in color.

Type ♀ from Sibulan River (Angan Falls, 3,000 ft.), Nov. 11, 1930; another female from the three from the Galog River (6,000 ft.), September, October and May. One male from the Galog River (6,000 ft.), October 22, 1930.

This is a very distinct species on account of the peculiar configuration of the abdominal segments in the female.

Phalacrotophora (*Omapanta*) **pallidicornis** sp. nov.

♀. Length 3.0 mm. Front pale reddish brown, the ocellar area blackened; antennæ and palpi very pale, nearly white; mesonotum yellowish in front shading to piceous behind; scutellum black; pleuræ testaceous, with a brown area near the root of the wing; abdominal tergites black, the third and fifth behind and the sixth at the sides and all of the seventh brownish yellow; legs entirely testaceous; wings faintly brownish, the veins dark and strong; halteres dark, with the tip of the knob whitish. Front three-fifths as broad below as high, slightly widened above, its surface smooth and polished; two small postantennal bristles separated by one-fourth the width of the front, set much lower than the very large antial bristles which are midway between them and the eye-margin; bristles of lower frontal row placed near the eye-margin well below the middle of the front; præocellar row with the middle pair much reduced in size, separated by less than one-third the width of the front and placed just below the ocellus, the lateral bristles of this row much larger, set near the eye, just above the upper third of the front so that this row forms a moderately curved line; bristles of ocellar row strong. Cheek with one moderately strong bristle and several more in a series extending to the antenna. Antennæ and palpi small; the latter with weak bristles below toward the tip. Mesonotum shining, with black appressed hairs; two dorsocentral bristles with four smaller bristles between them; scutellum with four strong bristles. Pleuræ bare. Abdomen with all the tergites fully chitinized; second but little elongated; sixth strongly so, but of the usual form and with subopaque surface like the other tergites, as long as the three preceding segments and gradually narrowed behind; seventh half as long, tubular, with a row of bristly marginal hairs encircling it at the apical third; eighth highly polished with a number of very irregularly placed stiff bristly hairs scattered over its apical half. Second segment without lateral tuft of bristles, but at the hind angles with a group of short bristly hairs, repeated also on the third segment. Front tibiæ with a row (double on the apical half) of short strong cilia and a group of about six short dorso-posterior spines at apex; middle tibiæ with two rows of bristles; hind tibiæ similarly armed, the bristles about as long as the width of the tibia. Costa reaching clearly beyond the middle of the wing (6 : 11); its cilia minute; second section four-fifths as long as the second; third very short as the third vein is forked very near the apex to form a very small, almost linear cell; light veins all practically straight the fourth clearly bisinuate; seventh long.

Type from the Sibulan River (7–8,000 ft.), September 21, 1930.

This species is readily distinguishable from *P. scutata* by the normally formed abdominal tergites and by the chætotaxy of the front, as well as by the characters in wing venation as indicated in the key.

Phalacrotophora irregularis sp. nov.

♀. Length 1.9 mm. Black; the antennæ piceous, reddish brown at the base of the third joint; front legs, middle trochanters and hind coxæ luteous; palpi pale yellow; wings slightly brownish, with dark brown veins. Front two-thirds as broad as high, shining, but not polished, the surface microscopically shagreened and sparsely hairy; ocellar tubercle faintly elevated, the median frontal line faintly indicated; four postantennal bristles, the lower pair nearly as long as the upper which occupy nearly one-third the width of the front; antial bristles near to the eye, a little above the level of the upper postantennals, directed straight upwards; lowest lateral bristles next to the eye, far above the antials, at the lower third of the front; preocellar row of four bristles forming a straight transverse line at the upper third of the front; cheek with two strong divergent bristles below and a close set series of delicate ones extending upward along the eye toward the antenna. Antennæ not enlarged; palpi rather small, with short, stout bristles. Mesonotum rather shining, with very short, soft pubescence which becomes bristly near the scutellum. One pair of dorsocentral bristles; scutellum large, nearly semicircular, with two long marginal bristles. Mesopleura sparsely hairy above, with one large bristle at the upper posterior corner. Abdomen with six tergites, all fully sclerotized, but the sixth is very short and is exposed behind the fifth only as a narrow band; remainder of abdomen soft, pointed at apex; surface subshining; side margins with very short bristles, conspicuously longer on the second tergite. Legs stout; the front tarsi slender; hind tibiæ with two rows of stout bristles, one on each side of the hairseam, those of the inner row as long as the width of the tibia and those of the outer row about half as long. Costa extending to the middle of the wing (40 : 78), its bristles short and very closely placed; first section slightly longer than the second and three times as long as the third (16 : 13 : 5); fork of third vein acute, the second and third veins not widely separated, both curving upwards to the costa; fourth vein nearly straight, weakly bent near base and faintly recurved at each end; fifth bent near base, very slightly and evenly divergent from the fourth; sixth and seventh nearly straight.

Type from the Mainit River (5,000 ft.), Mt. Apo, Mindanao, Philippines, November 5, 1930 (C. F. Clagg).

This species will not fit into any of the three subgenera recognized by Schmitz since the abdomen of the female is fully sclerotized and the mesopleura bristly. It thus combines characters of both Phalacrotophora, *s. str.* and Omapanta.

PLASTOPHORA Brues

Ann. Mus. Hist. Nat. Hongrois, vol. 3, p. 551 (1905).
Schmitz. Monog. Phoriden, p. 152 (1929).

There is a single species in the collection that appears to belong to this genus which is by no means very distinct from Megaselia. On this account, it is included in the key to species of that genus.

Plastophora dubitata sp. nov.

♀. Black or piceous, the mesonotum dark brown and the pleuræ lighter brown; palpi brownish yellow; front legs testaceous, the middle and hind ones fuscous with the tarsi somewhat paler; wings faintly tinged with brown, the veins fuscous; halteres pale yellowish. Front very slightly wider than high, subshining with very sparse fine pubescence; bristles very long, slender; four postantennal bristles, the lower pair much smaller than, but not much nearer to one another than the upper ones which occupy nearly one-third the width of the front;

antial bristles midway between the median line and the eye margin, set at the level of the upper postantennals and much below the lowest lateral bristles; preocellar row of four equidistant bristles forming a line that is bowed downwards medially; ocellar tubercle very prominent, the median frontal groove clearly defined. Antennæ small, with a slender, nearly bare arista. Palpi with moderate bristles at tips and very small ones on the lower edge. Proboscis broad, narrowed to a blunt tip reaching to the tips of the palpi and heavily chitinized when seen from below. Mesonotum strongly convex, with one pair of long slender dorsocentral bristles; two somewhat longer bristles on the broad, short scutellum which is twice as wide as long. Mesopleura above with a patch of sparse small bristles and two strong backwardly directed bristles arising at the middle and lower corner of the patch. Abdomen with dull surface, the tergites of about equal length, not much narrowed until the sixth which is sharply narrowed to a rounded tip. This segment bears a fringe of six or eight bristly hairs near the apex, about as long as the segment and directed posteriorly; beyond this there projects a slightly asymetrical process, shorter than the sixth tergite which is inserted slightly to the left of the median line and is directed toward the right; this is shining black and bears scattered bristly hairs. Legs moderately slender; hind tibia with the posterior hair-seam sharply angled at the middle, its base arising nearer the external side of the tibia than usual; one series of setulæ inside the seam; these short and weak, especially on the basal half of the tibia. Wings rather narrow, but not especially long; costa extending to a little beyond the middle, its cilia short and closely placed; first section of costa equal in length to the second; second vein completely absent; mediastinal vein showing as a faint trace by transmitted light; fourth vein bent at base, straight beyond, fifth vein faintly curved; sixth and seventh feebly sinuate.

Type from Lalun Mts. (6,500 ft.), Davao Province, Mt. Apo, Mindanao, Philippines, December 31, 1930 (C. F. Clagg).

I am somewhat in doubt as to the sex of the type, but believe it is probably a female as the projecting appendage at the tip of the abdomen does not appear to be a hypopygial lamella and no hypopygium is visible; also the chitinized proboscis is apparently always characteristic of females in this family. However, I cannot be positive on this point. The generic position may also be incorrect. The chætotoxy and other structural characters, aside from the simple third vein would place it perfectly well in Megaselia, but it is certainly very similar to the type species of Plastophora from New Guinea, and not close to any of the described species of Megaselia in which the second vein is weakly developed or absent.

JOHOWIA Silva

1916 Bol. Mus. Nac. Chile, vol. 9, p. 19.
1923 Borgmeier, Arch. Mus. Nac. Rio de Janeiro, vol. 24, p. 341.
1925 Borgmeier, *ibid.*, vol. 25, p. 182.
1929 Schmitz, Revision der Phoriden, p. 86, 142.

There is a single specimen from the Philippines which I have referred at least tentatively to this genus. Johowia is based on two South American species which I do not know in nature and as there are considerable differences in frontal chætotaxy which are not readily reconciled with the descriptions of the neotropical forms, it is quite possible that the Philippine type may be generically distinct.

Johowia setosissima sp. nov.

♀. Length 1.6 mm. Black with a distinct piceous or brownish tinge; legs piceous, the front pair slightly lighter beyond the coxæ; wings uniformly brownish, with very dark, strong venation. Front as wide as high at the middle; very deeply excavated on each side by the antennal cavities so that the anterior lobe of the front between the antennal cavities is two-fifths as high as the front above the cavities; this lobe narrowed below, its tip rounded (about like the tip of the antenna) and furnished along each side with four strong bristles which curve outwards over the antennæ and very slightly downward, in addition with one pair of smaller proclinate postantennal bristles which are scarcely divergent and separated by less than one-third the width of the front; antial bristles very slightly above the postantennals, curved toward the median line and somewhat nearer to the eye than to the postantennal bristle; lowest lateral bristle well above the antial and very close to the eye; præocellar row nearly straight, the median pair nearer to one another than to the lateral bristle; all bristles strong and well developed. Front with very distinct median line, dull, clothed with scattered small hairs. Antennæ very small, rounded, with a nearly bare arista as long as the headheight; palpi short, with strong apical bristles as long as the palpus; cheeks each with four or five long upcurved bristles along the edge close to the eye margin. Mesonotum short, no longer than wide, with a single pair of long dorsocentral bristles; two scutellar bristles, the scutellum much wider than long; mesopleura with a group of stiff hairs above, but without any long bristle. Abdomen with three tergites, the second not noticeably lengthened; remainder of abdomen membranous although the two apical segments are more distinctly chitinized than the intermediate portion. Legs slender, the hind femora less than one-third as broad as long; spurs of four posterior tibiæ long and slender; hind tibiæ with a dorsal hair-seam and a very weak line of posterodorsal setulæ. Costa extending to distinctly beyond the middle of the wing, its cilia short and closely placed; first section of costa as long as the second and third together; third half as long as the second; fork of third vein very acute. Fourth vein evenly curved, not recurved at tip; fifth curved only near middle; sixth curved before the middle and faintly recurved near tip; seventh long, very slightly curved.

Type from the Galog River (5,000 ft.), September 26; Mount Apo, Mindanao, Philippines (C. F. Clagg).

This species is practically a Megaselia aside from the peculiar median lobe of the front which is much extended downwards and provided with the four extra pairs of bristles as described above. From their position these could hardly be regarded as supernumerary postantennal bristles and I am not all sure that this bristling is really similar to that in Johowia. However, the species should be easily recognizable.

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Vol. 70, No. 10—March, 1936

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RECORDS OF MEETINGS

One Thousand Two Hundred and Sixteenth Meeting

OCTOBER 10, 1934—STATED MEETING

The Academy met at its House at 8.20 P. M.

The PRESIDENT in the Chair.

There were present eighty Fellows and four guests.

The records of the annual meeting of May 9 were read and approved.

The Corresponding Secretary reported the receipt of letters accepting Fellowship from Edgar Anderson, C. G. Campbell, J. M. Clark, C. J. Connick, F. H. Crawford, O. G. C. Dahl, S. F. Damon, W. M. Daniels, C. L. Dawes, J. P. Den Hartog, J. F. Ebersole, G. C. Evans, S. P. Fergusson, C. H. Fiske, R. E. Freeman, J. F. Fulton, E. S. Furniss, R. M. Haig, A. M. Harmon, Hudson Hoagland, J. C. Hunsaker, Henry Jackson, Jr., D. F. Jones, M. B. Jones, E. W. Kemmerer, H. P. Kendall, R. G. Kent, F. H. Knight, Kurt Koffka, C. C. Little, R. M. MacIver, L. W. McKeehan, D. H. Menzel, R. S. Meriam, H. A. Millis, H. R. Mimno, L. M. S. Miner, A. E. Monroe, E. L. Moreland, P. M. Morse, W. H. Newhouse, E. G. Nourse, W. A. Oldfather, Leigh Page, R. H. Pfeiffer, W. C. Quinby, A. N. Richards, Oscar Riddle, D. M. Robinson, C. G. A. Rossby, A. H. Ruggles, E. H. Schell, T. L. Shear, E. W. Sinnott, G. M. Smith, L. B. Smith, F J. Teggart, L. M. Terman, C. F. Thwing, E. L. Thorndike, J. H. Van Vleck, Jacob Viner, Leo Wolman, D. E. Worrall, L. C. Wroth, and C. C. Zimmerman; of letters accepting Foreign Honorary Membership from Gustav Cassel, R. A. Fisher, A. V. Hill, Arthur Holmes, Paul Janet, Serge Koussevitzky, Luigi Lombardi, P. B. Struve, and Richard Willstätter; also of letters declining Fellowship from A. G. Keller and S. H. Schlichter; and of letters resigning Fellowship from G. L. Hosmer and R. L. O'Brien.

The Corresponding Secretary announced that the Council had made the following grants from the Permanent Science Fund:

1. A grant of $300 to Joseph A. Cushman, Director of the Cushman Foraminiferal Laboratory, Sharon, Mass., to assist in preparing slides of the foraminiferal fauna from the samples obtained by the ship "Atlantis" belonging to the Oceanographic Institute.

2. A grant of $750 to C. V. Green and C. C. Little, Roscoe B. Jackson Memorial Laboratory, Bar Harbor, Maine, for the care of experimental animals and the preparation and study of microscopic sections of tumors in their work on cancer research.

3. A grant of $250 to William J. Luyten, Associate Professor of Astronomy, University of Minnesota, to be spent on technical assistance in an investigation of the proper motions of faint stars in the southern hemisphere.

4. A grant of $375 to Bret Ratner, Clinical Professor of Pediatrics and Lecturer in Immunology, New York University and Bellevue Medical College, to aid in the continuation of his experiments on asthma in the guinea pig.

5. A grant of $100 to Roberts Rugh, Hunter College, New York City, for the purchase of material needed for the study of induced ovulation and egg transport in the Urodeles and for the preparation of moving picture films of this process.

6. A grant of $300 to Mrs. Mabel Ruttle Nebel of the New York Agricultural Experiment Station, Geneva, N. Y., to make it possible for her to continue her study of the chromosome matrix in plants of Allium, Crepis, Hordeum, Tradescantia, and Zea under various temperatures and nutritive conditions.

7. A grant of $250 to Karl Sax, Associate Professor of Plant Cytology, Harvard University, as a contribution of one-half the cost of building a constant temperature chamber, where the effect of variations between 5° and 40° C. on certain cytological processes can be studied.

8. A grant of $100 to Harry R. De Silva, Professor of Psychology, Massachusetts State College, Amherst, to assist in the purchase of electrical supplies to finish an A.C. bridge and to improve a D.C. bridge, which will be used to study any existing relations between metabolism as measured by the gasometric method, body voltage as measured by the D.C. bridge, and body impedance as measured by the A.C. bridge.

9. A grant of $750 to V. M. Slipher, Director of the Lowell Observatory, Flagstaff, Arizona, to aid in continuing his work on the spectra of the planets.

The President announced the death of seven Fellows:—Nathaniel Lord Britton (Class II, Section 2), George Cary Comstock (Class I, Section 1), Richard Thornton Fisher (Class II, Section 2), Henry Roseman Lang (Class IV, Section 3), Odin Roberts (Class III, Section 1), George Byron Roorbach (Class III, Section 3), William Hultz Walker (Class I, Section 3).

The Fellows elected in May were then presented to the Academy.

The following communication was presented:

Mr. Leigh Hoadley: "The Experimental Analysis of Animal Development," with lantern illustrations.

The following papers were presented by title: "A Study of the Ant Genera Novomessor and Veromessor," by W. M. Wheeler and W. S. Creighton; "The Apparatus and Method used for the Measurement of the Compressibility of Several Gases in the Range 0° to 325° C.," by J. A. Beattie; "New Bands of the Ionized Nitrogen Molecule," by F. H. Crawford and P. M. Tsai; "The Relation of the Eyes to Chromatophoral Activities," by G. H Parker, F. M. Brown, Jr., and J. M. Odiorne; "The Melting Curves and Compressibilities of Nitrogen and Argon," by P. W. Bridgman.

The meeting was dissolved at 9.50 P. M.

One Thousand Two Hundred and Seventeenth Meeting

NOVEMBER 14, 1934—STATED MEETING

The Academy met at its House at 8.25 P. M.

The PRESIDENT in the Chair.

There were present sixty-three Fellows and ten guests.

The records of the meeting of October 10 were read and approved.

The Corresponding Secretary reported the receipt of a letter from Robert E. Park accepting election as a Fellow.

He also announced the appointment of Professor Arthur E. Kennelly to continue as representative of the Academy in the Division of Foreign Relations of the National Research Council for the three-year period ending June 30, 1937; and of Professor Henri Pirenne as delegate of the Academy at the celebration of the Centenary of the Founding of the Royal Commission of History of Belgium at Brussels, November 28, 1934.

The President announced the following deaths: Samuel Parsons Mulliken (Class I, Section 3) and Raymond Poincaré, Foreign Honorary Member in Class III, Section 4.

The following communication was presented:

Mr. P. A. Sorokin: "The Movement of Internal Disturbances in the History of Ancient Greece, Rome, Byzantium, and Seven of the Main European Countries," with lantern illustrations.

The meeting was dissolved at 9.50 P. M.

One Thousand Two Hundred and Eighteenth Meeting

DECEMBER 12, 1934—STATED MEETING

The Academy met at its House at 8.25 P. M.

The PRESIDENT in the Chair.

There were present forty-two Fellows and four guests.

The records of the meeting of November 14 were read and approved.

The President announced the death of four Fellows: Gilman Arthur Drew (Class II, Section 3), Ernest Gale Martin (Class II, Section 3), Allan Winter Rowe (Class I, Section 3), Theobald Smith (Class II, Section 4); and of one Foreign Honorary Member, Willem de Sitter (Class I, Section 1).

The following communication was presented:

Mr. W. Lloyd Warner: "The Religion of a Stone Age People."

One paper was read by title: "Measurements of Certain Resistances, Compressibilities, and Thermal Expansions to 20,000 Kilograms per Square Centimeter," by P. W. Bridgman.

The meeting was dissolved at 9.50 P. M.

One Thousand Two Hundred and Nineteenth Meeting

JANUARY 9, 1935—STATED MEETING

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present fifty-one Fellows and eight guests.

The records of the meeting of December 12 were read and approved.

The President announced the death of two Fellows: George Pierce Baker (Class IV, Section 4) and Roland Burrage Dixon (Class IV, Section 2); and of two Foreign Honorary Members: Mineichiro Adatci (Class III, Section 2) and Georg Elias Müller (Class IV, Section 1).

On the recommendation of the Council an additional appropriation was made of fifteen dollars for Library expenses from the General Fund for the current year.

The following communication was presented:

Mr Arthur Loveridge: "The Kruger National Park and a Visit to Mount Debasien and Mount Elgon, Uganda," illustrated with motion pictures.

The following paper was read by title: "The Dependence on the Boundary of the Boundary Values of the Potential and its Derivatives," by Oliver D. Kellogg and Mildred M. Sullivan.

The meeting was dissolved at 9.50 P. M.

One Thousand Two Hundred and Twentieth Meeting

FEBRUARY 13, 1935—STATED MEETING

The Academy met at its House at 8.25 P. M

VICE-PRESIDENT CANNON in the Chair.

There were present fifty-five Fellows and three guests.

The records of the meeting of January 9 were read and approved.

The Corresponding Secretary reported the receipt of a letter from Mr. Charles J. Bullock, resigning Fellowship.

He also announced the receipt from the Belgian Royal Commission of History of a silver medal commemorating its Centennial Celebration.

The Vice-President announced the death of three Fellows: Herdman Fitzgerald Cleland (Class II, Section 1), William Cushing Wait (Class III, Section 1) and James Haughton Woods (Class IV, Section I).

The following communication was presented:

Mr. Earnest A. Hooton: "Man's Past, Present, and Future."

Three papers were read by title: "Observations on the Behavior of Animals during the Total Solar Eclipse of August 31, 1932," by William Morton Wheeler, Clinton V. MacCoy, Ludlow Griscom, Glover M. Allen, and Harold J. Coolidge, Jr.; "Hecataeus and the Egyptian Priests in Herodotus, Book II," by William Arthur Heidel; "The Lower Permian Insects of Kansas, Part 7," by F. M. Carpenter.

The meeting was dissolved at 9.50 P. M.

One Thousand Two Hundred and Twenty First Meeting

MARCH 13, 1935—STATED MEETING

The Academy met at its House at 8.30 P. M.

The PRESIDENT in the Chair.

There were present forty-four Fellows and two guests.

The records of the meeting of February 13 were read and approved.

The Corresponding Secretary announced that the President had appointed William H. Weston, Jr. and Karl Sax to represent the Academy at the Sixth International Botanical Congress, to be held at Amsterdam in September 1935; and Maurice Caullery to act as delegate to the Tercentenary Celebration of the National Museum of Natural History, Paris, to be held in June 1935.

The President announced the death of five Fellows: William Duane (Class I, Section 2), Ephraim Emerton (Class IV, Section 2), Michael Idvorsky Pupin (Class I, Section 2), Jeremiah Smith, Jr. (Class III, Section 4) and David White (Class II, Section 1).

The President appointed the Nominating Committee as follows:

Harry E. Clifford, of Class I
Oakes Ames, of Class II
George G. Wilson, of Class III
Charles Hopkinson, of Class IV

On the recommendation of the Council the following appropriations were made for the ensuing year:

From the income of the General Fund, $7,575, to be used as follows:

for General and Meeting expenses	$ 800
for Library expenses	2,200
for Books, Periodicals, and Binding	1,500
for House expenses	2,000
for Treasurer's expenses	1,050
for use at the discretion of the President	25

From the income of the Publication Funds, $2,645.52, to be used for publication.

From the income of the Rumford Fund, $3,230, to be used as follows:

for Research	$ 2,000
for Books, Periodicals, and Binding	350
for use at the discretion of the Committee	880

From the income of the C. M. Warren Fund, $900, to be used at the discretion of the Committee.

The following communication was presented:

Mr. Tenney L. Davis: "Ko Hung, Chinese Alchemist of the Fourth Century," illustrated with lantern slides.

One paper was read by title: "Studies in the Bromeliaceae. VI," by Lyman B. Smith, presented by B. L. Robinson.

The meeting was dissolved at ten P. M.

One Thousand Two Hundred and Twenty Second Meeting

April 10, 1935—Stated Meeting

The Academy met at its House at 8.25 P. M.

The President in the Chair.

There were present thirty-eight Fellows and six guests.

The records of the meeting of March 13 were read and approved.

The Corresponding Secretary reported that the Council had made the following grants from the Permanent Science Fund:

1. To Frank M. Carpenter, Museum of Comparative Zoology, Cambridge, $350, for expenses in connection with a collecting expedition to Kansas for the purpose of adding material necessary for his work on a Revision of the Lower Permian Insects of Kansas.

2. To Tenney L. Davis, Massachusetts Institute of Technology, $300, for technical assistance in the preparation and analysis of certain compounds essential to the completion of his study of the reactions of phosphorus trichloride with cuprous chloride.

3. To Fred W. Emerson, New Mexico Normal University, Las Vegas, $100, for aid in defraying expenses in connection with the study of the plant associations in the White Sands area near Alamogordo, N. M., and in collecting material for the study of palisade cells in desert plants

4. To Walter S. Hunter, Clark University, Worcester, $150, for apparatus, assistance, and other expenses to be incurred in investigating the inhibition and disinhibition of conditioned reflexes in human subjects.

5. To J. W. McBain, Stanford University, Cal., $250, for materials and equipment to be used in a study of adsorption in the air-water interface of various solutions.

6. To Arthur H. Graves, Brooklyn Botanic Garden, N. Y., $250, to help meet expenses in an investigation designed to produce a chestnut resistant to *Endothia parasitica*.

7. To Professor Robert Weill, of the Faculty of Sciences of the University of Paris, $300, for aid in defraying expenses of a visit to

the Bermuda Biological Station to study the nematocysts of Coelenterates.

It was also announced that the President had appointed Professor Maurice Caullery as delegate to the celebration of the Third Centenary of the Muséum d'Histoire Naturelle, Paris, on June 24, 1935; and Dr. William Morton Wheeler as delegate to the Twelfth International Zoological Congress at Lisbon in September 1935.

The President announced the death of two Fellows: George Hoyt Bigelow (Class III, Section 4) and Edwin Arlington Robinson (Class IV, Section 4).

The following communication was presented:

Mr. William J. Crozier: "Determinism and Biological Variability," illustrated with lantern slides.

The meeting was dissolved at 9.40 P. M.

One Thousand Two Hundred and Twenty Third Meeting

May 8, 1935—Annual Meeting

The Academy met at its House at 8.20 P. M.

The President in the Chair.

There were present sixty-two Fellows and seven guests.

The records of the meeting of April 10 were read and approved.

The Corresponding Secretary reported the receipt of a letter from Dr. Milton J. Rosenau resigning Fellowship.

The following report of the Council was presented:

REPORT OF THE COUNCIL

Since the last report of the Council there have been reported the deaths of twenty-four Fellows:—George Pierce Baker, George Hoyt Bigelow, Nathaniel Lord Britton, Herdman Fitzgerald Cleland, George Cary Comstock, Roland Burrage Dixon, Gilman Arthur Drew, William Duane, Ephraim Emerton, Richard Thornton Fisher, Henry Roseman Lang, Ernest Gale Martin, Samuel Parsons Mulliken, Michael Idvorsky Pupin, Odin Roberts, Edwin Arlington Robinson, George Byron Roorbach, Allan Winter Rowe, Jeremiah Smith, Jr., Theobald Smith, William Cushing Wait, William Hultz Walker, David White, James Haughton Woods; and four Foreign Honorary Members:—Mineichiro Adatci, Georg Elias Müller, Raymond Poincaré, Willem de Sitter.

Seventy Fellows and nine Foreign Honorary Members were elected by the Council and announced to the Academy in May 1934.

The roll now includes 761 Fellows and 121 Foreign Honorary Members (not including those elected in May 1935).

The annual report of the Treasurer, Ingersoll Bowditch, was read, of which the following is an abstract:

GENERAL FUND

Receipts

Income on hand April 1, 1934		$3,642.28	
From Investments	$2,740.33		
From Assessments	4,090.00		
From Admissions	340.00		
From Rumford Fund Income	200.00	7,370.33	$11,012.61

Expenditures

Assistant Librarian	$2,000.00		
Expenses of Library	66.17		
Treasurer's Expenses	940.90		
Books and Binding	1,546.90		
General Expenses	840.75		
House Expenses	2,354.15		
President's Expenses	20.00	$7,768.87	
Income transferred to Principal		355.75	$ 8,124.62

RUMFORD FUND

Receipts

Income on hand April 1, 1934	$ 640.28	
From Investments	3,401.00	$ 4,041.28

Expenditures

Purchase and Binding of Books	$ 444.44		
Research	2,629.28		
Transferred to General Fund Income for care of books	200.00		
Transferred to Publication Account	150.00	$3,423.72	
Income transferred to Principal		170.00	$ 3,593.72

Publication Account

Receipts

Income on hand April 1, 1934		$3,781.43	
From Income—Appleton Fund	$1,135.92		
From Income—Centennial Fund	1,740.56		
From Income—Rumford Fund	150.00		
From Authors' Reprints	1.50		
From Sale of Publications	380.56		
From Grants and Donations	600.00		
From Amer. Council of Learned Societies a/c Lake Publication Fund	4,000.00		
From Lake Fund subscriptions	1,053.03	9,061.57	$12,843.00

Expenditures

Publications—				
General Fund	$4,013.63			
Rumford Fund	399.89			
Lake Fund	5,753.86	$10,167.38		
Vault Rent—part		4.40	$10,171.78	
Interest on Bonds bought		$ 22.69		
Income transferred to Principal		130.80	153.49	$10,325.27

C. M. Warren Fund

Receipts

Income on hand April 1, 1934		$ 21.29	
From Investments		933.90	$ 955.19

Expenditures

Research	$ 751.50		
Vault rent—part	2.20	$ 753.70	
Interest on Bonds bought	$ 2.08		
Income transferred to Principal	43.25	45.33	$ 799.03

FRANCIS AMORY FUND

Receipts

Income on hand April 1, 1934	$ 873.97	
From Investments	2,781.20	$3,655.17

Expenditures

Publishing Statement	$ 75.75	
Interest on Bonds bought	17.66	
Vault rent—part	6.60	$ 100.01

PERMANENT SCIENCE FUND

Receipts

Income on hand April 1, 1934	$1,000.00	
Received for above fund	6,315.00	$7,315.00

Expenditures

Grants from above fund		$7,065.00

The following reports were also presented:

REPORT OF THE LIBRARY COMMITTEE

During the year 95 volumes and 17 unbound numbers of serials have been borrowed by 10 Fellows and 12 libraries, and more have been consulted at the Academy. All books taken out have been returned or satisfactorily accounted for, with one exception, and this we expect to adjust on the borrower's return from abroad.

The number of volumes on the shelves at the time of the last report was 43,946. During the year 400 volumes were added, largely by binding serials, making the number now 44,346. This includes 43 purchased from the General Fund, 25 from the Rumford Fund, and 332 received by gift or exchange.

Mrs. M. F. Ball, who is the working librarian, has continued her regular and intelligent service throughout the year. During her twelve and one-half years service she has not been absent through sickness. She helps in the conduct of Academy affairs in many ways beyond a librarian's routine duties.

The following appropriations were placed at the disposal of the Librarian during the past year:

Balance from General Fund	$ 429.61
Balance from Rumford Fund	160.92
Appropriation from General Fund	3,515.00
Appropriation from Rumford Fund	350.00
Total	$4,455.53

The expenses charged to the library during the financial year ending March 31, 1935, were:

Salaries		$2,000.00
Binding:		
General Fund	$ 537.30	
Rumford Fund	74.95	612.25
Purchase of Books and Periodicals:		
General Fund	$1,009.60	
Rumford Fund	369.49	1,379.09
Miscellaneous		66.17
		$4,057.51

There remained an unexpended balance of $398.02, as follows:

General Fund	$ 331.54
Rumford Fund	66.48
	$ 398.02

In accordance with the usual custom this balance will be carried over to next year. Moreover I think that in view of uncertainties of exchange and other factors, I shall ask for $100.00 more than last year to be used if needed.

Respectfully submitted,
ALFRED C. LANE, *Librarian.*

May 8, 1935.

REPORT OF THE RUMFORD COMMITTEE

The Rumford Committee held four meetings during the Academy year (April 1, 1934 to March 31, 1935) on April 11, October 10, December 12, 1934, and February 13, 1935.

The Committee made the following grants, during the year, from the Rumford Fund, in aid of researches in light and heat.

1934	*No.*		*Amount*
Apr. 11	314	Prof. P. W. Bridgman, Harvard University, for Equipment in Researches on Thermal and Optical Properties of Matter	$ 400
Apr. 11	315	Prof. J. C. Stearns, University of Denver, for Equipment in Cosmic-ray Research	300
Apr. 11	316	Dr. C. E. Bennett, Mass. Inst. of Technology, for Equipment in Research on Refractive Index of Gases under Varied Impressed Conditions	400
Oct. 10	317	Prof. D. C. Stockbarger, Mass. Inst. of Tech., for Equipment in Research on Growth of Optical Crystals	400
Oct. 10	318	Dr. C. E. Tester Jr., 109 Maple St., Waverly, Mass., for equipment in Research on the Joule-Thomson Effect	100
Dec. 12	319	Dr. Bart J. Bok, Harvard University, for Equipment in Research on Radial Velocities in the Spectra of Faint Stars	400
1935			
Feb. 13	320	Prof. J. R. Roebuck, University of Wisconsin, for Equipment in Research on Thermal Properties of Gases	149.36
Feb. 13	321	Dr. J. A. Bearden, Johns Hopkins University, for Equipment in Research on X-rays	400
		Total	$2,549.36

It may be mentioned that the research of Grant No. 317 ($400) in the foregoing list, in conjunction with Grant No. 302 ($500) of December 14, 1932, has eventuated in an application for U. S. Letters Patent. So far as we have information, this is the first scientific research aided by a Rumford Grant that has led to a patent application since the Academy appointed the Rumford Standing Committee in 1833. At the request of the Council, the Committee has covered the matter in a brief special report to the President and Council, dated April 30, 1935.

The following recent publications concern researches aided by Rumford Grants.

P. W. Bridgman—"The Melting Curves and Compressibilities of Nitrogen and Argon." *Proc. Am. Acad. Arts and Sciences,* Vol. 70, No. 1, March 1935.

R. H. Frazier—"Precise Speed Control for D-C Machines." *Electrical Engineering,* March 1935.

W. R. Fredrickson, C. R. Stannard—"Magnetic Rotation Spectrum of the Red Bands of Sodium." *Physical Review,* Vol. 44, pp. 632–637, Oct. 15, 1933.

Willi M. Cohn—"Preliminary Report of the Expeditions for Observing the Total Solar Eclipses of August 31, 1932 and February 14, 1934." *Pub. of the Astron. Society of the Pacific,* Vol. XLVI, No. 272, Aug. 1934.

Willi M. Cohn—"Polarisation and Spectrum of the Sky Light during the Total Solar Eclipses of August 31, 1932 and February 14, 1934." *Nature,* Vol. 134, p. 99, July 21, 1934.

Willi M. Cohn—"Some Observations of the Sky Polarisation during the Total Solar Eclipses of August 31, 1932 and February 14, 1934." *Physical Review,* Vol. 45, No. 11, June 1, 1934.

J. R. Roebuck, H. Osterberg—"The Joule-Thomson Effect in Helium." *Physical Review,* Vol. 43, No. 1, January 1, 1933.

J. R. Roebuck, H. Osterberg—"The Thermodynamic Properties of Helium Gas." *Physical Review,* Vol. 45, No. 5, March 1, 1934.

Reports of progress in research have been received from the following grantees: C. E. Tester Jr., D. C. Stockbarger, H. T. Stetson, N. H. Kent, F. E. Ross, J. Schilt, A. G. Worthing, C. Payne, A. C. Hardy, W. R. Fredrickson, C. E. Bennett, R. F. Frazier, Joel Stebbins, G. R. Harrison, and W. J. Luyten.

Respectfully submitted,
ARTHUR E. KENNELLY,
Chairman.

May 8, 1935.

REPORT OF THE C. M. WARREN COMMITTEE

The Committee had at its disposal at the beginning of the fiscal year 1934–1935, \$840.04, of which \$753.70 has been expended during the past year, leaving a balance of \$86.34.

Since the last annual report grants have been made as follows:

May 19, 1934: To Professor I. M. Kolthoff, University of Minnesota, \$200, to continue his study of internal structural changes taking place in freshly formed crystalline precipitates.

May 19, 1934: To Dr. Gordon H. Scott, Washington University, \$200, to continue his work on the nature and distribution of inorganic salts in cells and tissues.

May 19, 1935: To Dr. Hermann Schmid, Technische Hochschule, Vienna, \$150, to continue his work on the photometric measurements of short-lived intermediate products.

May 19, 1935: To Dr. Charles E. Teeter, Jr., \$200, to purchase supplies to aid in carrying out an accurate measurement of the Joule-Thomson coefficient and heat capacity at constant pressure for methane.

Eight applications for grants totaling \$1790 are before the Committee for consideration.

Reports of Progress, during the current year, have been received from: C. F. H. Allen, Nelson K. Richtmeyer, Hermann Schmid, Carl L. A. Schmidt, W. E. Bradt.

The papers listed below, which have been published since the last report of the Committee, describe the results of investigations aided by the Warren Fund. In each case there is an acknowledgment by the author of the assistance received.

Nelson K. Richtmyer and Raymond M. Hann—"Glucosidohydroferulic Acid." J. Am. Chem. Soc., **57**, 227 (1935).

Nelson K. Richtmyer and Eleanor H. Yeakel—"The Structure of Populin." J. Am. Chem. Soc., **56**, 2495 (1934).

C. F. H. Allen, J. B. Normington and C. V. Wilson—"Certain Reactions of Gamma Ketonic Acids." Canadian Journal of Research, **11**, 382–394 (1934).

C. F. H. Allen and J. A. Scarrow—"The Addition of Cyanoacetamide to α-Methoxybenzal-acetophenone." Canadian Journal of Research, **11**, 395–405 (1934).

Nelson K. Richtmyer—"The Cleavage of Glycosides by Catalytic Hydrogenation." J. Am. Chem. Soc., **56,** 1633 (1934).

JAMES F. NORRIS, *Chairman.*

May 8, 1935.

REPORT OF THE COMMITTEE OF PUBLICATION

The most important event in the history of the Committee of Publication during the year 1934–35 is the inauguration of a new series of publications by the Academy—the Monumenta Palaeographica Vetera.

The first series of this publication consists of "Dated Greek Minuscule Manuscripts to the year 1200" by Mr. and Mrs. Lake. In the plates, which are accompanied by an explanatory text, representative pages of these ancient manuscripts are reproduced by the collotype process in the exact size of the originals. Two fasciculi of this series are displayed on the table, with the other publications of the year, for examination by the Academy. Two fasciculi to be issued during the year 1935 are now in type, and it is expected that six more (two published annually) will be required to complete the first series.

The Academy has received aid for the publication of this series by generous grants from the American Council of Learned Societies, and we are much indebted to Messrs. Christophers of London for their care in handling the foreign subscriptions without compensation. The edition is 300 copies, and the subscriptions received are—domestic 32 and foreign 48, making a total of 80.

Another monumental work issued by the Academy during the year is the Memoir by Dr. Cleveland and his associates. This is illustrated by sixty beautiful plates dealing with the life-history of a remarkable wood-feeding roach and its symbiotic protozoa. It appeared as Part 2 of Vol. 17 of the Memoirs, completing that volume. For aid in the publication of this work the Academy received a grant from the Permanent Science Fund.

Vol. 18 of the Memoirs will begin with a Memoir, to appear this month, which is an extensive treatment of certain mathematical functions by the late Oliver D. Kellogg and Miss Mildred M. Sullivan. This will be followed by Part 2 of Vol. 18, now about to go to press, consisting of a Memoir on Hecataeus by Mr. Heidel.

Of the Proceedings there have appeared since the last annual meeting eight numbers of Vol. 69 and three of Vol. 70. Of these two were printed with aid from the Rumford Fund. The fourth number of Vol. 70, by Mr. Carpenter, will appear this month.

The Committee has held four meetings and has had numerous conferences by mail and telephone during the year. Ten manuscripts have been accepted for publication, and four were rejected. The Committee has voted to limit the edition of the Memoirs to 500 copies, and has started plans for a second series of the Monumenta Palaeographica Vetera, details of which are not yet ready for announcement.

For convenience in accounting, the receipts and expenditures on account of the Dated Greek Manuscripts are kept separately as the "Lake Publication Fund." The amounts received and expended by the Committee during the fiscal year that ended March 31st, are shown in the following statements:

General Publication Fund 1934–35

Receipts			
Balance April 1, 1934			$2,998.97
Appropriation 1934–35			3,017.77
Rumford Fund, unexpended balance		$ 249.89	
Rumford Fund, grant 1934–35		150.00	399.89
Gifts: Permanent Science Fund		$ 500.00	
Anonymous		100.00	
Bond Astron. Club		25.00	625.00
Sale of Publications			348.31
Other receipts			80.52
			$7,470.46
Expenses			
Transferred to Lake Publication Fund			$1,000.00
Printing: Memoirs Vol. 17, No. 2		$1,721.74	
Proceedings, Gen'l Fund	$1,870.68		
Proceedings, Rumford Fund	399.89		
		2,270.57	
Total printing			3,992.31

Binding Proc. Vol. 68		28.35
Other expenses, postage, trucking, etc.,		397.26
Balance April 1, 1935		2,052.54
		$7,470.46

Lake Publication Fund 1934–35

Receipts

General Publication Fund		$1,071.77
American Council of Learned Societies		2,000.00
Subscriptions received, less discounts		1,111.05
Due from London agent, Mar. 31, 1935 (approximate) £46/6/– at $4.85		224.55
Deficit 1934–35 (approximate)		115.93
		$4,523.30

Expenses

Prospectus		$ 361.33
Plates, Fasc. I	$1,424.37	
Plates, Fasc. II	1,365.99	2,790.36
Text and binding Fasc. I	$ 582.21	
Text and binding Fasc. II	600.44	1,182.65
Other expenses paid		166.95
Due London agent for expenses to Mar. 31, 1935 (approximate) £4/10/10 at $4.85		22.01
		$4,523.30

For the year 1935–36 the Lake Publication Fund has been credited with $500 transferred from the General Publication Fund, and it has received a grant of $2,000 from the American Council of Learned Societies.

ROBERT PAYNE BIGELOW, *Chairman.*

May 8, 1935.

Report of the House Committee

The House Committee has had funds at its disposal amounting to $3,149.90, made up as follows:

Balance from previous year	$ 721.90
Appropriations for 1934–35	2,200.00
Received for use of rooms	228.00
Total	$3,149.90

Of this amount the sum of $2,212.94 has been spent for the routine expenses, janitor, light, power, heat, telephone, etc., and $369.21 has been spent for upkeep and equipment, making a total of $2,582.15, and leaving an unexpended balance of $567.75.

The two largest items in the expenditure for upkeep were $110 for painting the outside walls of the stack building and $103.62 for repairs on its roof and drain pipe.

In February of this year the acoustics of the Lecture Hall were greatly improved by covering the ceiling with sound absorbent material. The cost of this does not appear in the accompanying figures, since it was met from the Contingent Fund.

Meetings have been held as follows:

American Council of Learned Societies	1
The Academy	8
American Antiquarian Society	1
American Chemical Society, Northeastern Section	6
Archaeological Institute of America, Boston Society	2
Geological Society of Boston	4
Japan Society of Boston	1
Mediaeval Academy of America	1
New England Botanical Club	9
Total	33

The Council Chamber has been used for the Academy Council and Committee meetings, and also by the Trustees of the Children's Museum, the New England Farm and Garden Association, etc.

A detailed list of expenditures follows:

Janitor	$ 970.00
Electricity: Light	231.07
Power	66.74
Fuel	612.93
Elevator	90.65
Gas	59.20
Telephone	109.80
Water	46.00
Ash tickets	11.88
Upkeep	321.63
Furnishing and equipment	47.58
Janitor's supplies and sundries	14.67
Total	$2,582.15

Respectfully submitted,
S. Burt Wolbach, *Chairman.*

May 8, 1935.

On the recommendation of the Treasurer, it was *Voted,* That the annual assessment for the ensuing year be ten dollars.

The annual election resulted in the choice of the following officers and committees:

Roscoe Pound, *President*
James Flack Norris, *Vice-President for Class I*
Walter Bradford Cannon, *Vice-President for Class II*
Edwin Francis Gay, *Vice-President for Class III*
Arthur Stanley Pease, *Vice-President for Class IV*
Tenney Lombard Davis, *Corresponding Secretary*
Walter Eugene Clark, *Recording Secretary*
Ingersoll Bowditch, *Treasurer*
Alfred Church Lane, *Librarian*
Joshua Whatmough, *Editor*

Councillors for Four Years

Dugald C. Jackson, of Class I Arthur N. Holcombe, of Class III
Ralph H. Wetmore, of Class II Kenneth J. Conant, of Class IV

Finance Committee

Thomas Barbour Paul J. Sachs Alfred L. Ripley

Rumford Committee

Arthur E. Kennelly, *Chairman*

Elihu Thomson
Percy W. Bridgman
Harry M. Goodwin
Charles L. Norton
Harlow Shapley
Norton A. Kent

C. M. Warren Committee

James F. Norris, *Chairman*

Gregory P. Baxter
Walter L. Jennings
Arthur D. Little
Frederick G. Keyes
Reid Hunt
Charles A. Kraus

Committee of Publication

Joshua Whatmough, *Chairman*

Edwin C. Kemble, of Class I
Frederic T. Lewis, of Class II
Joseph H. Beale, of Class III
Robert P. Blake, of Class IV

Committee on the Library

Alfred C. Lane, *Chairman*

Raymond C. Archibald, of Class I
Thomas Barbour, of Class II
Nathan Isaacs, of Class III
Henry B. Washburn, of Class IV

Auditing Committee

George R. Agassiz
Alexander Forbes

House Committee

S. Burt Wolbach, *Chairman*

William H. Lawrence
Robert P. Bigelow
Davis R. Dewey

Committee on Biographical Notices

Davis R. Dewey, *Chairman*

James F. Norris
Alfred C. Lane
Walter E. Clark
Joseph H. Beale
Samuel E. Morison

Committee on Meetings

The President
The Recording Secretary
Harlow Shapley
Leigh Hoadley
Abbott P. Usher
Joshua Whatmough

The Corresponding Secretary announced that the following had been elected members of the Academy:

FELLOWS

CLASS I

Section 1.	Gilbert Ames Bliss, Chicago, Ill.
Section 2.	Charles Elwood Mendenhall, Madison, Wis.
	Floyd Karker Richtmyer, Ithaca, N. Y.
	Robert Jemison Van de Graaff, Cambridge
	Bertram Eugene Warren, Cambridge
Section 3.	Louis Harris, Cambridge
	Nicholas Athanasius Milas, Belmont

CLASS II

Section 1.	Oliver Lanard Fassig, San Juan, Porto Rico
	Warren Judson Mead, Cambridge
	Derwent Stainthorpe Whittlesey, Cambridge
Section 2.	Bernard Ogilvie Dodge, New York, N. Y.
Section 3.	Charles Henry Blake, Cambridge
	John Franklin Daniel, Berkeley, Cal.
	Karl Friedrich Meyer, San Francisco, Cal.
Section 4.	Tracy Jackson Putnam, Brookline

CLASS III

Section 1.	James Brown Scott, Washington, D. C.
Section 2.	Tyler Dennett, Williamstown
	Charles Grove Haines, Los Angeles, Cal.
Section 4.	Jerome Davis Greene, Cambridge
	Henry Lee Shattuck, Boston

CLASS IV

Section 1.	Clark Leonard Hull, New Haven, Conn.
	Henry Alexander Murray, Jr., Boston
	Robert Sessions Woodworth, New York, N. Y.
Section 3.	Charles Henry Beeson, Chicago, Ill.
	Robert Johnson Bonner, Chicago, Ill.
	Tenney Frank, Baltimore, Md.

Benjamin Dean Meritt, Baltimore, Md.
Henry Washington Prescott, Chicago, Ill.
Henry Arthur Sanders, Ann Arbor, Mich.
Section 4. Walter Raymond Spalding, Cambridge

FOREIGN HONORARY MEMBERS

Class II

Section 2. Sir William Wright Smith, Edinburgh

Class III

Section 3. Luigi Einaudi, Turin, Italy
John Maynard Keynes, Cambridge, England
René Maunier, Paris, France
S. Rudolph Steinmetz, Amsterdam, Holland

The following communication was presented:

Mr. Jerome D. Greene: "Japan's Position in Manchuria."

The meeting was dissolved at ten o'clock.

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HENRY LARCOM ABBOT (1831–1927)

Fellow in Class I, Section 4, 1863

Henry Larcom Abbot, Fellow of the American Academy of Arts and Sciences, and of the National Academy of Sciences, Brigadier General, Corps of Engineers, U. S. Army, and an internationally famed engineer, was born at Beverly, Essex County, Massachusetts, August 13, 1831. He died at Cambridge, Massachusetts, Oct. 1, 1927, aged 96 years. He traced his descent through his father, Joseph Hale Abbot, a teacher of Cambridge, his grandparents Esra and Rebekah (Hale) Abbot of Wilton, New Hampshire, and through a line of ancestors devoted to the interests of community, church, and country, to George Abbot of Andover, Massachusetts, who settled there from England in 1642. Rebekah Hale, his grandmother, was niece of Captain Nathan Hale, "martyr-spy of the Revolution." On his mother's side, General Abbot was the grandson of Captain Henry Larcom of Beverly, who followed the sea throughout a long life. General Abbot's mother, Mrs. Fanny Ellingwood (Larcom) Abbot, was a granddaughter of Nathan Dane, LL.D., of the Continental Congress 1785–1788, framer of the famous Ordinance of 1787, and founder of the Dane Professorship of Law at Harvard University. General Abbot was the eldest of seven children.

Such was the ancestry of General Abbot. In his own countenance and character shone out the quiet scholarly life. Though not in the least lacking in social charm, he went little in society, preferring the study, where throughout his life he engaged in research, and in the preparation of papers, giving both to the technical and to the lay public the results of his investigations.

General Abbot entered West Point on July 1, 1850, and was graduated, number two in his class, June 1854. As Second Lieutenant, he was assigned to the corps of Topographical Engineers, U. S. Army, and ordered on May 1, 1855, to report for duty to Lieutenant R. S. Williamson for explorations and surveys in Northern California and Oregon for locating a railroad to connect the Sacramento Valley with the Columbia River. This survey involved much hardship and danger. During a considerable part of it young Abbot was in command of the party. Hostile Indians, almost impossible terrain, and shortage of supplies combined to make great difficulties. Nevertheless he completed his task successfully and recommended almost the exact route later adopted in building the first railroad northerly through that section. His report shows the same careful attention to scientific observations, though not immediately required by the actual problem in hand, which ever after characterized his engineering work.

General Abbot owed his election to the scientific academies of which he early became a member to the extensive investigations of the flow of the Mississippi River and its tributaries, and the most suitable measures for its flood control, which he made in cooperation with Captain (afterwards Major General) A. A. Humphreys, in the years 1857 to 1860. Their report is a classic in river hydraulics.

It is difficult to give an adequate idea of the comprehensive character of this extraordinary investigation. In it the authors aimed to accept no assumptions, but to satisfy every inquiry by exact measurements made under such a wide variety of conditions as to enable them to reduce the whole subject to accurate mathematical expression, so that estimates could be based with certainty thereon. The great task of the preparation and printing of the Mississippi River report was still occupying Lieutenant Abbot when the Civil War broke out in 1861. He managed to drive the book through the press in time to take part in the first battle of Bull Run, where he was seriously wounded, and brevetted captain for "gallant and meritorious services." Soon recovering from his wound, he was continuously in service and rapidly promoted so that at the age of thirty-three years he commanded a brigade of troops in the field.

During the Civil War, General Abbot took part in McClellan's Peninsular Campaign as Aide-de-Camp to General Barnard; was Chief Engineer to Banks' expedition to the Gulf; commanded regiment and brigade south of Washington, Feb. 1863–May 1864; commanded Siege Artilleries operating against Richmond, June 1864–Jan. 1865; was Chief of Artillery, Fort Fisher Expedition, Aug. 1, 1864; was promoted Bvt. Brigadier General U. S. Volunteers for gallant and meritorious services before Richmond, and Mar. 13, 1865, Bvt. Colonel, U. S. Army, and Bvt. Major General, U. S. Volunteers, "for gallant and meritorious services during the Rebellion."

General Abbot's war observations of the effects of mining operations both terrestrial and submarine, and his experience in the command of siege artillery during the operations against Richmond, led him to conclusions which he embodied in an important paper, No. 14 of the Professional Papers of the Corps of Engineers.

Soon after the war, an Engineer School of Submarine Mining was established at Willets Point, New York, which General Abbot commanded for many years. During this period he published many papers giving the results of his investigations on explosives, submarine mining, the use of electricity and of fuses for firing explosives, and on related subjects. He had charge of the channel-deepening blasting at Hell Gate in 1885, and seized the opportunity to establish stations at various distances, and in different directions, so as to determine the velocity of transmission of earth tremors.

During the last seven years of his active service, General Abbot was president of the permanent Board of Engineers in New York to which were referred the more important questions which came under the attention of the Chief of Engineers. He was retired for age in 1895, being then ranking officer of the Corps of Engineers, but not receiving the appointment as Chief. He was for many years thereafter associated with the faculties of George Washington University and Dartmouth College.

Soon after his retirement from active duty, General Abbot was invited in 1897 to be Chief Engineer of "La Compagnie Nouvelle du Canal de Panama." He took the leading part in the investigations which it undertook to rescue the abortive project of the Old Panama Company begun under de Lesseps.

The plan perfected by an international committee of consulting engineers having been approved by the New Company, General Abbot had the honor of being the only foreign member included in the French Commission which was set up for putting the plan into execution. The proposal debated about 1899 in the Congress of the United States for constructing an interoceanic canal through Nicaragua forced the New Company to enter into negotiations with our Government for the sale of their equities in Panama. General Abbot's investigations had thoroughly convinced him of the greater practicability of the Panama route. His forceful testimony tended to move Congress and the Executive to prefer that route, although there was a strong prejudice in high quarters against dealing with the French Company. The Walker Commission, appointed by President McKinley, at first reported favorably to the Nicaragua route, but when the French Company reduced its price to $40,000,000, the Walker Commission changed its report to prefer Panama.

During the next several years a tangle of diplomatic and other interests held the question in the balance, with General Abbot publishing from time to time powerful articles in favor of a high-level lock canal at Panama. In the end he convinced Senator Mark Hanna, as well as Senator Spooner, and Secretary of War Taft; and finally, on June 21, 1906, General Abbot's preferred type of canal was authorized. Many additional details of this and other concerns of General Abbot's, during his effective engineering career of more than 50 years, will be found in the Biographical Memoir, Vol. XIII, First Memoir, 1929, of the National Academy of Sciences.

General Abbot married April 2, 1856, Mary Susan Everett of Cambridge, Massachusetts, who died March 13, 1871, aged 39 years. They had four children, two sons and two daughters.

General Abbot was very gentle and loving in his home life, though so deeply immersed in his unremitting researches and military duties as not very easily to be drawn into social intercourse; not a talkative man, he was a good listener, with face alight with kindly interest, when actually drawn out of his computations, and brought into the social circle. He received the reverence and warm affection due to an unblemished, kindly, generous character.

CHARLES G. ABBOT.

MINÉITCIRO ADATCI (1870–1934)

Foreign Honorary Member in Class III, Section 2, 1932

Minéitciro Adatci was born in Yamagata, Japan, July 29, 1870, and died at The Hague, December 28, 1934. After graduating in law at the University of Tokyo in 1892, he soon entered the diplomatic service and served in the different lower grades abroad, with duty from time to time in the Ministry for Foreign Affairs in Tokyo. He acted as Chargé d'affaires at Rome and at Paris. Appointed Minister to Mexico in 1912 he served till 1915, and then for two years on missions to Russia. In 1916 he was made Minister to Belgium and in 1920 Ambassador to Belgium, but was transferred as Ambassador to France in the same year.

Mr. Adatci was elected a Judge of the Permanent Court of International Arbitration in 1924. He had previously found time to serve as judge of the Prize Courts at Sasebo and Yokosuka during the Russo-Japanese war, 1904–1905, and as a member of the committee which drafted the peace treaty at Portsmouth in 1905. He was a delegate to the Peace Conference at Paris, 1919; he aided in drafting the Statute of the Permanent Court of International Justice in 1920; he was a delegate of Japan to the League of Nations Assembly; and from 1927 to 1930 he represented Japan in the Council of the League of Nations, as well as from time to time in many other capacities.

Mr. Adatci was elected a member of the Permanent Court of International Justice in 1931 and immediately became President, serving in that capacity from January 16, 1931, to December 31, 1933, and he remained a member of the Court till his death.

Mr. Adatci was a member of many learned societies, among them the Japanese Academy, and the Institute of International Law; he was also an honorary member of the American Society of International Law.

Mr. Adatci's genial and cultured personality as well as his wide and sound learning gained many friends both for himself and for his country.

He reverenced the Permanent Court of International Justice, referring to it in his opening address in 1931 as "the living embodiment of the conception of peace based on law," and added "The conception endures, and the institution remains, but men change."

GEORGE G. WILSON.

JOHN SPENCER BASSETT (1867–1928)

Fellow in Class III, Section 3, 1921

Few writers and editors in the field of American History have done so much to stimulate intensive study and publication in the field of learning which they have adorned as John Spencer Bassett. A North Carolinian by birth, a graduate of Trinity College, a Doctor of Johns Hopkins—both southern institutions— he was later connected as a teacher in the historical field with four northern universities and colleges: Yale, New York, Columbia, and Smith, in which last he was a professor at the time of his accidental and lamented death in 1928.

Not many American scholars have had such a breadth of training and of experience. He was by nature a good teacher, a good investigator, a good writer. As a good editor he directed and combined historical and literary work by other scholars.

Bassett's early experience made him throughout his life especially interested in southern antebellum social and economic organization. He was the author of several publications on the actual conditions of slavery and its effect on the life of master and slave, particularly on the North Carolina plantations. He also published volumes on the colonial beginnings of the southern colonies and wrote two biographies of southern-born Presidents—Andrew Jackson and Abraham Lincoln. He was a man who could take part in coöperative enterprises, and one of his best volumes is his *Federalist System*, a part of the *American Nation* series.

His interests were not tied up in the difficulties and solutions of the past. When the great crisis of the World War came on in 1914 he addressed himself to two volumes on the relation of the United States to the European struggle and the later League of Nations.

This enumeration of his contributions to the literature of American History, included in more than twenty separate volumes, was only a part of his service to his country. Through his classroom teaching, his contact with student minds, his editorial work, his executive capacity as secretary of the American Historical Association, and his contact with writers and journalists and eager young men and young women who came under his influence, he became a recognized force in the writing and teaching of American History.

Few American scholars have shown such breadth of training and of experience. He was by nature a good teacher, a good investigator, a good writer, a good leader, and a good friend. He could work in harness with other people, and he could lay out historical and literary work for other scholars to perfect. Loyal to the South throughout his life, he was equally loyal to the North and to the West. Bassett was an all-round man, to whom the fraternity of historical, political, and economic scholars owes a debt which can only be repaid by applying his principles of research and judgment and personal influence. He was *integer uitae*.

ALBERT BUSHNELL HART.

GEORGE HOYT BIGELOW (1890–1934)

Fellow in Class III, Section 4, 1933

George Bigelow was son of a fine old type of general practitioner, Dr. Enos H. Bigelow of Framingham. His father was always interested in public affairs. He served a few terms in the state legislature and he was interested in preventive medicine and public health. Probably the son George got his impetus towards public health from his father. He graduated from Harvard College as of 1913. He took his senior year in the Medical School, getting his M.D. in 1916. He served as interne in medicine at the Massachusetts General Hospital, did some war service, and he got his degree of Doctor of Public Health also from Harvard in 1921. His personal experience in medicine and public health was extensive. He studied the patient in the wards of the hospital. He studied various diseases in the laboratories. He studied yaws, for example, in the tropics. In 1921 he went out to Antioch College in Yellow Springs, Ohio, to be head of the Department of Industrial Medicine and Hygiene. Following that, he came to New York to be the director of the Cornell Clinic in New York City. In 1924, he was persuaded to come back to Massachusetts to be the director of the Division of Communicable Diseases in the State Department of Public Health. With the death of the Commissioner, he was appointed Commissioner of Public Health in Massachusetts in 1925, which position he occupied until 1933. In 1934, he undertook the directorship of the Massachusetts General Hospital and Massachusetts Eye and Ear Infirmary. He served in this capacity rather less than a year when he died suddenly by his own decision. Dr. Bigelow had made in a relatively few years a tremendous impression upon the public health of this country. He was unusual in the first instance because he was trained for his work. He came to his work with the best training of the time and brought with it a vigor and a mental capacity which at the present time, at least, is without parallel. He had additional attributes which made him outstanding, his complete mental honesty and fearlessness. Of great value to himself and to the public was his sense of humor. Public health is too often a dull, dreary, uninteresting area inhabited by arid facts and harrassed, conscientious public servants of mediocre intelligence. Bigelow's writings and sayings put a dazzling search-light upon the area of public health and his lively imagination peopled this area with living, interesting, delightful things. Moreover, his love of a well turned phrase or a humorous twist was always used to cap his points and not to divert them. In his scientific publications, of which there were many despite the arduous duties of a state executive, was shown only the vigor and intellectual honesty of the man. He developed a great Department of Public Health in Massachusetts, one that would rank with the old Massachusetts State Boards of Health with Lemuel Shattuck, Bowditch, and Walcott.

Just why Dr. Bigelow left the field of public health is not entirely clear. It is likely that he became conscious of the terrific strain that it involved and of course he must have had the satisfaction of having accomplished a real major task. When, after much hesitation, he decided to go into hospital administration work, that decision was hailed with the greatest enthusiasm by all those who were interested in hospitals, in the hospital problems, medical service, medical practice, and medical education. The hospital situation in general in this country needed just the qualities that Dr. Bigelow had in such abundance, but he was able only to make a start.

ROGER I. LEE.

JOHN CASPAR BRANNER (1850–1922)

Fellow in Class II, Section 1, 1921

Branner was born in New Market, Tennessee, July 4, 1850, and died March 1, 1922. He was of a leading Virginia family and one of the distinguished geologists of his day. His memoir by R. A. F. Penrose, Jr.[1] for the Geological Society of America, of which he was president in 1904, gives an excellent account of his work, and *Who's Who* (Vol XI, 1921–1922) lists his degrees (from the B.S. Cornell 1874, to the honorary Sc.D. Chicago 1916) and society memberships.

We may select the following facts as significant:

He was an authority on Brazil, where he worked from 1875 to 1883, and whither he frequently returned. Three out of five publications of the last year of his life pertained to Brazil.

From 1887 to 1893 he was director of the Arkansas Geological Survey. In this position he had the unusual distinction of being hanged in effigy for his discouragement of fraudulent alleged mines. He gathered about him there a group of men of marked distinction, whose reports, like that of R. A. Penrose on manganese (1891), and that of J. F. Williams on the igneous rocks, had much more than local value. He himself did much work on the bauxites, besides the detail work of a state geologist. From then on his bibliography of four hundred titles shows several papers a year, mostly on Brazilian and Arkansas geology, some of them in botany.

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[1] *Bull. Geol. Soc. of America*, 36, pp. 15–23, bibliography pp. 23–44.

After moving to California he became interested in seismology, when that subject was not popular among Californians, and with his money and energy really kept the Seismological Society alive through a difficult period.

Primarily a geologist, he also contributed studies in the fields of botany and entomology, and was a linguist of ability, not only in Latin and Greek, but also in Portuguese, the language in which he wrote a textbook for Brazilians, of which he wrote a grammar for English speaking people, and from which he translated a history of the Inquisition in Portugal.

From 1892 on he was connected with Leland Stanford University as professor of geology, acting president, president, and president emeritus. In reference to certain honors received he said that the greatest "was that of having those who had been his students doing good and honest work in every quarter of the globe." Thus a tribute after his own heart was that of Mr. and Mrs. Herbert Hoover, who met in his laboratory. In presenting a translation of De Re Metallica of George Agricola they dedicated it as follows: "To John Caspar Branner, Ph.D., the inspiration of whose teaching is no less great than his contributions to science."

A. C. LANE.

CHARLES HENRY BRENT (1862–1929)

Fellow in Class III, Section I, 1919

Charles Henry Brent was one of the outstanding Christian leaders of his generation. Born in New Castle, Ontario, April 9, 1862, the son of the Rev. Canon Henry and Frances Sophia (Cummings) Brent, he graduated from Trinity College, University of Toronto, in 1884. Ordained in 1886, he spent brief periods of service as an Assistant at St. Paul's Church, Buffalo, and St. John the Evangelist's, Boston. From 1891 to 1901 he was the Associate Rector of St. Stephen's Church, Boston, making during these years a deep spiritual impress upon the life of the city.

It was no surprise that in 1901 he was, as a result, elected to a position of great responsibility and of high adventure, the first Missionary Bishop of the Protestant Episcopal Church in the newly acquired Philippine Islands. It is not possible to summarize briefly the many years of his episcopate in the Philippines. Suffice it to state that he showed the highest type of Christian statesmanship in his pioneering field, winning the respect and affection of all, natives and foreigners alike.

At the same time, in his many trips to the United States, he became increasingly known as a man of spiritual power. He twice declined election to the Bishopric of Washington, D. C., and in 1914 he declined to become Bishop of New Jersey. In 1907, he was the William Belden Noble Lecturer at Harvard University. Long interested in the conquest of opium, he served as a member of the Philippine Opium Commission, 1903–1904, Chief Commissioner for the United States, and President of the International Opium Commission, 1908–1909, as well as of a similar conference at the Hague in 1911.

In 1918 he accepted election as Bishop of Central New York, and in the same year became Senior Chaplain of the American Expeditionary Force in France, for the duration of the War. He was awarded the D.S.M. by his own nation, and was made a Commander of the Order of Leopold, a Companion of the Bath, and an officer of the Legion of Honor.

After the War, he assumed his duties in Buffalo as Bishop of Western New York, in addition giving the Duff lectures in Scotland, and becoming a member of the Board of Overseers of Harvard University in 1921. But his great passion in the remaining years was for the cause of Christian unity. Though not well, he labored unceasingly for a united church, being President of the World Conference on Faith and Order.

Bishop Brent was the author of numerous volumes of sermons and essays. He was given honorary degrees by many universities and colleges, including Trinity College, King's College, Harvard, Columbia, Yale, Hobart, Glasgow, Union, Toronto, and the University of New York. He died at Lausanne, Switzerland, March 27, 1929.

Here is the record of important events in his life; but such a record cannot reveal him as he was. Only those who knew him will recall that indefinable quality in him which made eternal life a present and vivid reality.

HENRY KNOX SHERRILL.

JOHN ISAAC BRIQUET (1870–1931)

Foreign Honorary Member in Class II, Section 2, 1914

John Briquet was born at Geneva, Switzerland, March 13, 1870. He studied at universities in his native city, in Scotland and in Germany—an international education which gave him, among other things, an unusual facility in languages. On his return to Geneva in 1890 he was appointed a curator in the Conservatoire et Jardin Botanique and succeeded in 1896 to the directorship, a post which he held until his death, October 26, 1931.

Although a distinguished man of science and the recipient of many honors, Briquet was perhaps most generally known among his colleagues for that part of his work which was, from the strict standpoint of research, least important. When, in 1900, botanists became convinced that a serious effort to unify practice in nomenclature was necessary, the international congress of that year put him at the head of a committee to prepare a new set of rules for the purpose. With this matter he was concerned for the rest of his life. He brought to it a singular clarity and keenness of mind, excellent judgement, a friendly spirit and a polished literary style which could make the driest discussion (and the subject was rather arid) almost agreeable. Nomenclature is as necessary for mutual understanding in botany as grammar is in language; Briquet perceived the analogy and built his rules on such definite tendencies as could be discerned in the then rather chaotic state of usage. His code passed the congress of 1905 by a substantial majority; but a considerable group of Americans and individual theorists elsewhere refused to accept it. Some small additions were made to it in 1910. After an interval of twenty years, caused by the war, it was again taken up in 1930. This time it was, at the instance of British botanists led by Dr. T. M. Sprague and in the light of accumulated experience, extensively revised in detail; but the guiding hand was still Briquet's. And this time everyone accepted it. Whatever the matter, it was no mean achievement to have stood through thirty years steadily for reason and common sense and in the end to have brought the botanical world to his side.

Briquet was among the foremost botanical systematists and administrators of museums in Europe. As director of the Conservatory, he brought it up from a poorly lodged and disorganized, though already very valuable, collection to be one of the greatest establishments of its kind, pleasantly situated and well housed. As an investigator, he worked with distinction along many botanical lines. First of all a taxonomist, he endeavored always to broaden the base of his classification and to bring to its service whatever other branches of the science might have to contribute. His floras of the Maritime Alps and of Corsica (both, unhappily, still incomplete at his death), the fruit of many summers in the field, are philosophic studies of the plants of natural areas in their relations to taxonomy, phytogeography and geological history. His studies of the structure of the fruit in the families *Umbelliferae* and *Compositae* were of high importance in their field and contributed much to the understanding of previously obscure relationships.

C. A. Weatherby.

NATHANIEL LORD BRITTON (1859–1934)

Fellow in Class II, Section 2, 1925

Nathaniel Lord Britton was born at New Dorp, Staten Island, New York, January 15, 1859, and died in New York, June 25, 1934. As a young man, divided in his interest between botany and geology, he graduated from the School of Mines at Columbia, in 1879. There, under the influence of John Strong Newberry, he was encouraged to continue his botanical work. Upon graduation Britton became Assistant in Geology under Newberry; and for five years he was Botanist and Assistant Geologist of the Geological Survey of New Jersey; these years seeing the completion of his first extended botanical publication. In 1886 he became Instructor in Geology and Botany at Columbia, later advancing to Professor of Botany.

Convinced that the nomenclature of plants should be treated as a mechanical system, rather than as a language built up through selective good usage, Britton early took the lead of a so-called "radical" movement among some American botanists. To the changes of practice which seemed to him and his followers of paramount importance he devoted limitless energy and was everywhere recognized as the leader of his cause. The principles for which he stood were incorporated into his many volumes on the floras of eastern North America, Bermuda, the Bahamas and the West Indies and in his extensive monographic studies; and, although the majority of botanists of the world declined to accept his more radical departures from usage, he held tenaciously to his individual principles throughout more than forty productive years.

In the late 80's Dr. Britton and some of his associates formed a committee to consider the possible establishment of a botanic garden in the city of New York. Vigorously pushing this project the committee soon achieved success, and The New York Botanical Garden, with Britton as its Director-in-Chief, became an accomplished fact. The remarkable executive capacity of the Director, and his purpose to make the Garden indispensable to the community and a great center for botanical research, are abundantly attested by its growth to an area of 400 acres, by rich scientific output, and by the diversified staff of investigators and teachers who surrounded him at the end of his thirty-nine years as Director.

Soon after getting the New York Botanical Garden in successful operation Dr. Britton turned his attention to the West Indies. He made thirty visits for botanical exploration to various islands, in which he was accompanied by Mrs. Britton, herself a distinguished botanist, or by members of his staff. Future generations will remember him chiefly for his untiring and eminently successful efforts to establish a great Botanic Garden in the city of New York and for his intensive studies of the flora of the West Indies.

M. L. Fernald.

THOMAS CHROWDER CHAMBERLIN (1843–1928)

Fellow in Class II, Section 1, 1901

During the Christmas recess at the close of 1914, the Department of Geology at the University of Chicago expanded from the overcrowded Walker Museum into the just-completed Rosenwald Hall. On Christmas morning I spent a few hours in the small room beneath the eaves, which had been assigned to me as a graduate student, arranging books and fossils so that everything would be ship-shape for the continuation of my research after the chaos of moving-day. I thought I was alone in the building but suddenly a step sounded in the corridor and there at the open door of my room stood the genial figure of Professor Thomas Chrowder Chamberlin with a radiant smile on his benign countenance and a "Merry Christmas" on his lips. I was so astonished that I am afraid I failed utterly to make the orthodox reply and only gave voice to my surprise that he of all the members of the department should be in the building that day. His characteristically frank response was to the effect that "no day, not even Christmas, would be a happy one unless I wrote a few pages of manuscript or jotted down some notes concerning my research."

That little incident is indelibly impressed upon my mind. It reveals with complete accuracy the spirit of the man and affords a flash of insight concerning the secret of his success. Indefatiguable industry, unbounded love for the quest of knowledge, unending passion for intellectual adventure, and fond interest in the activities of the younger men associated with him either as students or colleagues—all these and more were displayed.

T. C. Chamberlin was born September 25, 1843, a few miles southwest of the site of the present city of Mattoon, Illinois, "on the crest of the Shelbyville terminal moraine." When he was about three years old, his "circuit-rider" father, by preference a Methodist minister and by necessity a farmer as well, moved the family to the vicinity of Beloit, Wisconsin. Here he "grew up in an atmosphere of serious and sharp debate in theology and philosophy." After his graduation from Beloit College in 1866, the next few years were spent in teaching in High School and Normal School, with a year of graduate study at the University of Michigan.

In 1873 the Geological Survey of Wisconsin was organized and Chamberlin was appointed assistant geologist. From 1876 to the completion of the Survey in 1882, he was chief geologist. The four volumes of the Survey's report, "Geology of Wisconsin," are models of pioneer geologic research, in which the chief geologist's contributions deal especially with the glacial deposits, the lead and zinc ores, and the Silurian coral reefs.

The study of the glacial features of Wisconsin led to the appointment of Chamberlin as geologist in charge of the glacial division of the United States Geological Survey in 1881, a post which he continued to occupy with great distinction and unqualified success until 1904. The series of notable memoirs by Chamberlin and his associates which appeared in rapid succession in the Annual Reports of the Director of the United States Geological Survey between 1882 and 1888 are among the classics of geological literature. Even after other duties began to consume his time, Chamberlin continued to direct the work of the glacial division which proved under his stimulating leadership to be a training field for faithful and painstaking observations and constructive interpretations in which more than a score of geologists, now well known and highly honored, were given a start in the right direction.

Chamberlin became President of the University of Wisconsin in 1887 and in the next five years transformed that institution from a college into a true university, both in organization and in spirit. Nevertheless, when in 1891 he was offered the headship of the department of geology to be organized in the new University of Chicago, he accepted "with a deep feeling of relief at being free from the burdens of the University presidency." From 1892 to 1918, Chamberlin devoted his energy unstintingly to the great institution of learning which developed with astounding rapidity in Chicago. In many ways he contributed to the revolutionary expansion of the University along scientific lines. Here he established the *Journal of Geology*, and here under his oversight there developed one of the greatest geological departments in any university, American or foreign, during the first two decades of the twentieth century.

At the close of the academic year in 1918, shortly before his seventy-fifth birthday, Professor Chamberlin retired from his University duties, continuing only his service as senior editor of the *Journal of Geology*. But retirement meant to him merely greater freedom for continuing his research, and the last ten years of his life were among the most fruitful. One of the finest of all his publications was *The Two Solar Families* which came from the press on his eighty-fifth birthday, a few weeks before his death, November 15, 1928.

The two hundred fifty one titles in the bibliography of Chamberlin's published works, which accompanies the biography by his son, Rollin T. Chamberlin, Biographical Memoirs, National Academy of

Sciences, vol. 15, pp. 309–407, 1934, indicate something of his breadth of interest and the scope of his mind. Among his numerous contributions to geological science, probably the most significant are those which deal with multiple glaciation of North America, geological climates, the age of the earth and sun, the origin of the earth, the origin of life, the evolution of the earlier vertebrates, the methods of geologic correlation, diastrophism, and the earth's interior. His name is indissolubly linked with the planetesimal theory of earth origin and the doctrine of multiple working hypotheses as the method for scientific attack upon a problem.

KIRTLEY F. MATHER.

HERDMAN FITZGERALD CLELAND (1869–1935)

Fellow in Class II, Section 1, 1911

Herdman Fitzgerald Cleland, Edward Brust professor of geology and mineralogy at Williams College, was born at Milan, Illinois, July 13, 1869, the son of David J. and Margaret (Betty) Cleland. He met a tragic death in the *Mohawk* disaster on January 24, 1935, while en route to Yucatan with a party of young men whom he was to guide in the study of the Mayan remains. Three of the students, all seniors at Williams, shared his fate.

Cleland was of Scottish and Irish ancestry. He inherited a tradition of culture, refinement and scholarship. His thrifty Scottish training was a lifelong advantage. He lived simply but well, always managing to set aside something to be used in helping others. President Tyler Dennett has said of him: "He was also generous, one of the most generous citizens of Williamstown, not in ostentatious ways, but quietly and simply as he lived. I am told that there is more than one family in our village, which, due to his help, now owns the roof over their heads. There are others, many of them, who learned that when in sore need they could find both sympathy and substantial help. A model teacher, he was in equal degree a model citizen."

Although quiet and reserved, Cleland had an infinite capacity for making friends, to whom his conversation was a delight. He was fastidious, physically and mentally, and was annoyed by much which he saw and read; but his criticisms generally emerged as witty remarks which did not sting; yet were so pointed that they often produced good results. He was forthright and frank, yet withal so just that he aroused no personal antagonism. The mass production of the lecture system did not appeal to him. He was profoundly interested in each of his students, ever ready with counsel, advice, and stimulus. That his students were well trained is attested by the records of the geologists who have graduated from Williams during the last thirty-three years. His instruction and his personality equally influenced a majority of his students who did not become professional geologists.

Cleland's early education was greatly delayed by the inadequacy of the schools in the small frontier town in which he passed his earlier years. He received a part of his preparatory training, and took two years of undergraduate work, at Gates College in Nebraska, but received his A.B. at Oberlin in 1894, where his interest in geology was fostered by the late Professor Alfred A. Wright. After graduation, ill health forced him to return for a year to the home of his father at Pierce, Nebraska. He attended the summer session of the University of Nebraska in 1895, and that fall entered upon the duties of professor of natural sciences at Gates College, where he remained three years. A summer at the University of Chicago in 1896 crystallized his leanings toward geology, and, realizing the difficulty of teaching all the natural sciences, he gave up his position at Gates College in 1898. That autumn he entered the graduate school at Yale, studying chiefly under Henry Shaler Williams, then the outstanding exponent of stratigraphic paleontology. He received his degree of doctor of philosophy there in June, 1900.

Cleland spent the ensuing year at Cornell, engaged in research and teaching. During Professor Harris's absence in the winter term, which he then devoted to his duties as state geologist of Louisiana, Cleland gave the courses, one of which was devoted to a detailed discussion of the fossil Brachiopoda.

In the autumn of 1901, he was called to Williams College, where he was instructor in geology and botany till 1904, assistant professor till 1907, when he became professor of geology and mineralogy. After teaching all the sciences, he was at last in a position to teach one. Even so his task was not simple. He had to build up a department and a museum. He succeeded in doing both.

Cleland's early researches were in the realms of paleontology and stratigraphy. His doctoral dissertation, published as a Bulletin of the U. S. Geological Survey, was a very detailed study of the distribution of the fossils in the Hamilton formations exposed along Cayuga Lake. He later described the fauna of the Mid-Devonian Strata at Milwaukee, Wisconsin, and also published two important papers descriptive of the Beekmantown fossils of the Mohawk Valley. He subsequently withdrew almost entirely from this field, devoting himself to his first textbook, "Physical and Historical Geology" (American Book Company, New York, 1916), and to other geological subjects, particularly the origin of natural bridges. His "Practical Applications of Geology and Physiography" (Excelsior Press, North Adams) appeared in 1920.

Later in his life his interests changed again. Numerous trips to Europe, some of them prolonged, brought him in contact with the vestiges of prehistoric civilizations. He took up particularly the study of the Neolithic and later ages, a part of the story of ancient man commonly considered to be outside the province of the geologist. This led to his interesting book, "Our Prehistoric Ancestors" (Coward-McCann, Inc., New York, 1928). His last work was a little volume entitled, "Why be an Evolutionist?" 1930.

Cleland was a fellow of the American Association for the Advancement of Science, the American Academy of Arts and Sciences, the Geological Society of America (councilor, 1928–1931), the Paleontological Society (secretary, 1909), the American Geographical Society, a member of the Seismological Society, the American Institute of Mining and Metallurgical Engineers, the American Archeological Society, the New York Academy of Science, of Phi Gamma Delta, of Sigma Xi, and of Phi Beta Kappa (honorary member).

He was married twice, first to Helen Williams Davison, and, after her death, to Emily Leonard Wadsworth. His widow, four daughters, a brother and a twin sister, Elizabeth, who has ever been his help in time of trouble, survive him.

The above sketch is an abridgment of one published by the writer in *Science*, Apr. 5, 1935. A longer notice, with complete bibliography and portrait, will appear in the *Proceedings of the Geological Society of America* in 1936.

PERCY E. RAYMONI

GEORGE CARY COMSTOCK (1855–1934)

Fellow in Class I, Section 1, 1913

Dr. George C. Comstock, professor emeritus of astronomy and director emeritus of the Washburn Observatory of the University of Wisconsin, died in Madison on May 11, 1934, in his eightieth year. In his passing we lose one of the last connections with American astronomy of fifty years ago, an investigator who was himself a leader in the science throughout his long career. He was distinguished as a teacher, an observer, a theorizer, an author, an organizer, and an administrator.

Comstock traced his ancestry on his father's side directly to the Mayflower. His grandfather moved from New England to Ohio in 1810, and his father was a resident of Madison, Wisconsin, when the future astronomer was born on February 12, 1855. The family moved to Michigan where Comstock spent his youth and prepared for college. Entering the University at Ann Arbor he took a scientific course and was graduated in 1877. While an undergraduate he came under the tutelage of Professor James Craig Watson, who was to influence his whole later life.

It was in 1854 that the German astronomer Francis Brünnow was called to Michigan. Trained in the traditions of his home institutions, Brünnow carried to a midwestern college the methods of a German university, and lectured in broken English to diminishing classes until Watson was his only student. Yet there was developed by Watson, who ultimately succeeded Brünnow, and the others at Michigan, the leading school for the study of astronomy in the country at that time. One of the foremost of the students was Comstock.

After several years as a civil engineer it was in 1881 that Comstock followed Watson to Wisconsin to be assistant in the Washburn Observatory. Then, after Watson's premature death, Comstock served at Madison under Edward S. Holden, later the first director of the Lick Observatory. As a career in astronomy involved considerable uncertainty, Comstock devoted his spare time to the study of law; he was graduated from the Wisconsin law school in 1883, but he never practised. Nevertheless, he later often referred to his legal training as possibly the most valuable part of his education.

At the age of thirty he was definitely committed to an academic career by an opening at Ohio State University, where he served as professor of mathematics for two years. In 1887, when Holden left to take up active service at the Lick Observatory, it was President T. C. Chamberlin who called Comstock to take charge of the Washburn Observatory. Watson and Holden had already given it a place of distinction in their science quite beyond that which would ordinarily be reached by a small observatory, and during the following thirty-five years Comstock maintained the quality of its work, both as its principal observer and as its administrator.

Throughout his scientific activity Comstock held an unusually happy balance between theory and practice. Though the observational astronomy of his early days consisted essentially of the visual measurement of angles he never became a routine observer. As a substitute for the meridian circle he adopted Loewy's method of placing a prism in front of a telescope, and by observing simultaneously stars separated by arcs of 120° the measures could be carried round the sphere in three steps, with the advantage that the quantities actually measured were small angles rather than large ones. From this work there resulted one of the best determinations of the constant of aberration ever made.

Comstock developed a simple formula for the amount of the atmospheric refraction which replaces in many cases the complicated procedure necessary for its evaluation. His measures of double stars were continued more than thirty years; the quality of his observations was always of the highest, exemplifying the statement that "the precision of a double-star measure bears no direct relation to the size of the telescope with which it is made." He contributed new methods of determining binary orbits, but the chief outcome of the double-star work was the detection of proper motions of faint stars.

One high authority on double stars had stated that there was yet to be brought forth any evidence of the proper motion of a really faint star, but Comstock demonstrated that stars as faint as the twelfth magnitude do move enough to be detected. By the remeasurement of faint companions of bright double stars, observed incidentally by the Struves and others early in the nineteenth century, he found that, when the known motions of the bright stars were allowed for, the remaining discrepancies were due to the motions of the faint ones. This conclusion was confirmed by a determination of the sun's way from the motions of the faint stars alone. From the average apparent motion of these stars, some five or six times fainter than had been previously studied, it was evident that they were nearer to us than would be inferred from their apparent brightness. Comstock gave two alternatives—either there is an appreciable absorption of light in space or the stars which he studied are intrinsically fainter than the bright ones. The second alternative has turned out to be the correct one, and the great preponderance of stars of low intrinsic luminosity in a given volume of space, which his work foreshadowed, has been amply confirmed in recent years.

Although Comstock held what was essentially a research position, he was an inspiring teacher of the few who came to study with him, due in large part to his mastery of clear and apt expression. In private conversation, in the classroom or at larger gatherings there was never any doubt of the meaning of his words, and the ease and finish of his speech was a source of constant admiration to his listeners.

One of the important measures of the first year of the administration of President Van Hise at the University of Wisconsin in 1904 was the definite organization of the graduate school. He selected Comstock to be the head of the school, and placed on him the task of working out the problems of a new division of the university, one that was growing rapidly both in size and in importance. He held this position until 1920, as chairman, director, and dean; showing in it his qualities of quiet efficiency and breadth of view. He received a school without definite organization and with about 150 students; he left it fully organized for teaching and for research and with its number nearly quadrupled. The duties of directing the graduate school naturally interfered with his scientific work during the later years, but on relinquishing the deanship he continued active, and finished and published the researches on which he had been long engaged.

Comstock received, as was his due, many honors from his fellows. He was a member of the National Academy of Sciences and of numerous other societies in this country and abroad. He was elected to the American Academy of Arts and Sciences in 1913. He was active in the organization of the American Astronomical Society and served for ten years as its first secretary; he was later recalled from retirement to be its president.

He retired from university service in 1922 and had the happiness of twelve years of active and interested leisure; and the satisfaction of seeing the continued progress of the university and the departments with which he had been connected.

JOEL STEBBINS.

See also article in *Popular Astronomy*, **43**, 1935, pp. 1–7.

ROBERT SEYMOUR CONWAY (1864–1933)

Foreign Honorary Member in Class IV, Section 3, 1931

Robert Seymour Conway, a Foreign Honorary Member of the Academy, was born at Walthamstow in 1864. He was educated at the City of London School, actually beginning his study of Sanskrit while still there; and (after a year at University College, London) at Gonville and Caius College, Cambridge, of which he was successively scholar, Fellow, and (after 1920) honorary Fellow. As an undergraduate he held the Waddington University Scholarship, took a first in both parts of the Classical tripos, and gained distinction in Part II of the tripos in Section E (Comparative Philology). In those days Comparative Philology was flourishing in Cambridge, and Conway, had he maintained his early devotion to it and been kept in Cambridge, could not have failed to make and keep it vital there. As it was he became Professor of Latin first in University College, Cardiff, and then (1903–1929) in the University of Manchester. His life work, therefore, was the teaching of Latin and the interpretation of Latin. As part of his work for the Cambridge tripos he had produced a dissertation on problems connected with intervocalic rhotacism in Italic, and before he left Cambridge he had started to work on his edition of the Italic dialect remains which appeared in 1897. Both in Cardiff and in Manchester he continued to teach Comparative Philology and the Italic dialects, and, on occasion, Sanskrit. But after about 1895, despite the translation of Brugmann's *Grundriss*, which he produced in collaboration with W. H. D. Rouse, despite his two works on the Italic dialects (the second being a handy selection of texts for students), and despite his numerous articles contributed to the eleventh edition of the *Enc. Brit.* on connected subjects, of which that on the Latin Language afterwards grew into a little book called the *Making of Latin*, Conway's other manifold interests and activities prevented him from advancing his own knowledge with the advance of Comparative Philology itself.

The loss to the study of Comparative Philology in England was great. At Cambridge Conway had come most under the influence of E. S. Roberts and of William Ridgeway, and he was no narrow logographer. His study of language, of Latin and kindred dialects in particular, was informed by a profound and vital human sympathy that enabled him to inspire an ancient text with a living interest that students and audiences everywhere found captivating. To the study of the language he always added the historical background of the people who spoke it, and brought them to life again. Before this achievement an occasional error of detail pales into insignificance. At Manchester, as previously at Cardiff, he exerted an enormous influence in favor of the Classics, and drew to himself, by the vigor of his forceful personality, a succession of students who afterwards went out as teachers into the schools ardent believers in the worth of the Classics, especially Latin, in a modern liberal education. This part of Conway's work will last long after him. With it must be reckoned also his long devotion to the Classical Association of England and Wales, as one of the founders, as secretary, as President, and also (for many years) as chairman of its Journals Board. He did yeoman service too in interpreting Latin authors, especially Vergil and Livy, to his own generation, not to scholars merely but to all sorts of men. To a young student, provided that he were willing to follow Conway's lead, Conway was ever generous, and he could and did many a time give a magnificent lead. Alert and active himself, he was intolerant of a slower pace in others, and sometimes impatient and quick tempered.

The list of his published work amounts to over a score of books and substantial monographs. Honors were numerous, and included honorary doctorates from Oxford, Padua, Dublin, and Manchester. He retired from active teaching in 1929, but already he had lectured in America, New Zealand, and Australia, and America he visited twice again. The year before his death he was Hibbert Lecturer. He was elected a Fellow of the British Academy in 1918. His edition of the Venetic inscriptions appeared posthumously, but he had himself completely revised it for the press and he was still actively engaged on his editions of Livy and of Vergil to within a month of his death which occurred in September 1933. There can seldom have been a teacher who has inspired his students with greater admiration for his methods and greater confidence in his knowledge than Conway did.

J. WHATMOUGH.

SAMUEL McCHORD CROTHERS (1857–1927)

Fellow in Class III, Section 4, 1913

Samuel McChord Crothers died at his home in Cambridge, Mass., on November 7, 1927. He was elected a fellow of the Academy on May 14, 1913, as a member of Class III, Section 4.

Dr. Crothers was born in Oswego, Ill., June 7, 1857. He took his A.B. at Wittenberg College in 1873. He received the same degree from Princeton in 1874. He studied at Union Theological Seminary, 1874–77; and at Harvard Divinity School, 1881–82. He received the honorary degree of D.D. from Harvard University in 1899, and the honorary degree of Litt.D. from St. Lawrence University in 1904, from Princeton University in 1909, and from Western Reserve University in 1923.

He was ordained to the Presbyterian ministry in 1877 and in the years following held pastorates at Eureka, Nev., 1877–78, Gold Hill, Nev., 1878, and Santa Barbara, Cal., 1879–81.

In 1882 he entered the Unitarian ministry and held pastorates at Brattleboro, Vt., 1882–86, St. Paul, Minn., 1886–94. He became minister of the First Parish in Cambridge in 1894 and continued in that office over thirty three years.

Dr. Crothers was essentially a liberty loving soul. He owed fealty only to the inner light, and to that most imperious of all centers of authority he was implicitly obedient. His patent sincerity, his disarming simplicity, his want of worldly sophistication, his power to penetrate shams, and his insight into realities made him a preacher of power, a pastor of wide sympathies, and a beloved author.

In an age which was moving steadily in the direction of specialized knowledge and at a time when churches were putting undue faith in organization, Dr. Crothers exalted by spoken and written word, as by example, that wisdom which is more precious than knowledge and more effective than mechanism.

He was known throughout the land for his books. These fell for the most part within the pattern of the essay. Through that restricted and difficult medium he found his best expression. He was the only one of his contemporaries in this country who reminded us of Charles Lamb and who was in some very real degree qualified to perpetuate the tradition of *Elia*. He allowed himself in the essay a genial play of humor, not untouched by subtle irony, which he forbade himself in the sermon. He refused to relax in the pulpit the high seriousness which he imputed to the preacher's office. This was with him a form of self-discipline in defense of an ideal. Those who knew him well discerned depths in the sermons, never plumbed by the essays, and loved the preacher even more than the essayist. His catholic Christianity found in the Unitarian ministry its most natural expression.

But to the wider world he was better known as the man of letters. He understood and loved America. He found the home of his maturity in New England and his genius had many affinities with the reserves and the understatement of the local tradition. But it was his mission, in part, to save us from provincialism and to spread before us the variety of American experience. His concern as a writer was with the *mores* of a people, their mental and moral second nature, their unrecognized idiosyncracies and their unsuspected possibilities. In so far as humor plays over his pages, it was invoked in the interests of an ultimate sobriety. He was never solemn, but he was always serious. He loved all sorts and conditions of men and had the power to make them see themselves, and, after the initial surprise, to believe in themselves. There was no root of bitterness in him, and his genial spirit—like the sun in the fable—was stronger than the blasts of reckless invective which have been sweeping back and forth across the country for the last half century.

Dr. Crothers was, in short, a humanist after the elder pattern, his humanism being rooted and grounded in a liberal faith in God. Whatever his day-by-day occupation or concern he was a minister of light and hope.

He married on Sept. 9, 1882, Louise M. Bronson of Santa Barbara, Cal. He is survived by his widow and by two daughters—Katharine and Marjorie, and two sons—Gordon and Bronson Crothers.

WILLARD L. SPERRY.

EDWARD SALISBURY DANA (1849–1935)

Fellow in Class II, Section 1, 1893

Edward Salisbury Dana was born in New Haven, Connecticut, November 16, 1849. He died in New Haven June 16, 1935.

The son of James Dwight Dana and Henrietta Frances Silliman, Dana inherited from both parents a strong scientific bent. From his school days in the Hopkins Grammar School in New Haven when he was already interested in botany to the end of his life, natural science was his major interest. And the field in which he labored most continuously throughout his long life was the administration and editing of the *American Journal of Science.* From 1875 until 1926, when it was turned over to Yale University, this journal was the property of the Dana family and was carried on by E. S. Dana, in spite of financial difficulties, as a family responsibility.

Dana graduated from Yale College in 1870 and then spent two years in the Sheffield Scientific School. The following two years were spent in European universities, chiefly at Vienna, where he established life-long friendships with his teachers. Returning to New Haven, he was made successively tutor in Mathematics, Physics and Chemistry, Assistant Professor in Natural Philosophy, and in 1890 Professor of Physics, holding that chair until his retirement in 1917. The most distinguished mineralogist that America has produced, Dana never held a chair in Mineralogy!

Dana's mineralogical publications began in 1872 while he was a student at Vienna. Without attempting to enumerate the many special papers and books on Mineralogy, Geology and Physics which followed, it is enough to mention here his greatest work, "The System of Mineralogy," published in 1892. This was the sixth edition of a work of like name, originally published in 1837 by his father. But the book was wholly rewritten and much enlarged over preceding editions. And so admirably was the work done and so exact was its presentation of the data of mineralogy that it at once took its place as the major work of reference in that science the world over. "The System" has well been called the Bible of Mineralogists. It is still, after forty-five years, the best available work of reference. The preparation of a new edition, now progressing slowly at the hands of a group of workers in the field, is guided by the express desire of mineralogists in every country that the essential form of the sixth edition be preserved as far as possible.

A detailed account of Dana's life and work at Yale, written by his colleague, Charles Schuchert, is to be found in the *American Journal of Science* for September 1935. A bibliography of his publications may be consulted in Bulletin 746 of the U. S. Geological Survey.

CHARLES PALACHE.

HUGO DE VRIES (1848–1935)

Foreign Honorary Member in Class II, Section 2, 1921

In 1918 the University of Amsterdam relieved from active duty a man who had directed its botanical activities for 32 years,—Hugo de Vries. He was a man whose attainments had brought him many distinctions, whose personality had brought him hosts of friends, a man whose experimental ingenuity had made possible two of the greatest generalizations of physical chemistry, and whose influence had induced the intellectual world to regard evolution as a matter capable of objective test rather than merely a rationalistic hypothesis. By his accomplishments, De Vries deserved this rest from arduous duty; but this was reckoning without the spirit of the man. Freedom from set duties was opportunity. He retired to Lunteren, built a laboratory, created an experimental garden, and went about his genetical work with the enthusiasm ordinarily expected only of youth. There he labored patiently for 17 years. And when death's call came on May 21, 1935, he had concrete plans for investigations that would have taken another decade to complete. Truly, here was a man!

Hugo de Vries was born in Haarlem, Holland, on February 16, 1848. His father was Secretary of the northern province and later Minister of Justice for the whole country. His mother was the daughter of Professor Reuvens of the University of Leiden. Thus his genetic inheritance and his environment were all that might be desired. As was to be expected, therefore, young De Vries showed early promise of attainment. At 13, he won a school prize for the best collection of plants from the vicinity of Haarlem, and at 21 he received a gold medal from the University of Groningen for an essay having the title "Über die Wirkung der Wärme auf der Wurzeln der Pflanzen."

De Vries obtained his doctorate from Leiden in 1870, at a time when war was still being waged over the *Origin of Species* issued by Darwin eleven years before; and, according to Stomps, the young man showed a sympathy with the new point of view that was not wholly agreeable to some of his teachers. After a post-doctorate year at Heidelberg under Hofmeister, De Vries returned to Holland and taught at the Hoogere Burger School and at the Handelschool in Amsterdam for four years. Every vacation during this period he spent in Würzburg with Sachs. His work at Würzburg resulted in a call to Germany to investigate certain physiological problems connected with the growing of the important crop plants, red clover, sugar beets, and potatoes. In 1877, he became privat-dozent at Halle under the distinguished plant pathologist, Julius Kühn. But he remained there only part of a year, returning to Amsterdam to become lecturer on plant physiology at the University. He continued his connection with Amsterdam University for 41 years as Lecturer, Professor Extraordinarius, Professor Ordinarius, and Director of the Botanical Institute.

De Vries had two separate careers in science, one as a physiologist and one as a geneticist. In each field he was an outstanding figure. In each he was a pioneer. He is better known in the department of genetics where he was a stimulating leader for 35 years; but it is quite possible that the historians of science will rate his contributions on turgor and osmosis as having the more lasting value. Such a judgement would not be strange. The early work in genetics necessarily involved phenomena where many variables were concerned, and tentative conclusions changed rapidly. But the work on cell physics and cell chemistry dealt with phenomena of an apparently simpler nature, where rigid control was feasible, and where interpretation was possible in the relatively static terms of the physical sciences.

The researches of De Vries, entitled Untersuchungen über die mechanischen Ursachen der Zellstreckung, published in 1877—together with the Osmotische Untersuchungen of Pfeffer, published the same year—led directly to van't Hof's generalization that the fundamental gas laws apply equally well to dilute solutions. Equally important contributions along the same line had great influence on the young Arrhenius in the preparation of his doctoral dissertation, where he enunciated the theory of electrolytic dissociation.

De Vries employed the living cell as the apparatus by which to study osmotic phenomena; and his plasmolytic method is still one of the most sensitive laboratory methods available to plant physiologists. By this means he was able to determine empirically the percentage of various dissolved substances which gave equivalent osmotic effects. There was great variation in the quantities necessary; and at first sight these quantities appeared to follow no law. But with sufficient data at hand, De Vries was able to show that isosmotic concentrations depend upon the solution of identical numbers of molecules. Thus when the number of grams of various substances indicated by their molecular weights is dissolved in a liter of water (G. M. solution), these solutions, if the cell membrane is permeable to them, give equivalent plasmolytic effects.

As a consequence of the establishment of the law that "equimolecular solutions are isotonic," it became possible to use the plasmolytic method for the determination of molecular weights of certain substances which at the time could not be fixed by chemical means. For example, chemists had suggested three different molecular weights for raffinose, viz., 396, 594, and 1188. De Vries proved that a 5.951 per cent solution is isotonic and therefore equimolecular with a 3.42 per cent solution of cane sugar. Raffinose is thus a trisaccharide having a molecular weight of $C_{18}H_{32}O_{16} + 5H_2O$.

While his interest in matters connected with osmosis was still at its height, De Vries began to be more actively concerned with the broader problems of variability, heredity, and evolution. He collected and studied variant material of a number of plant genera, and in the eighties began to make minute observations on controlled populations. One of the species which he found to be particularly intriguing, because of the type of variability shown, was a supposedly American evening primrose, Oenothera Lamarckiana. On this plant and its relatives, he concentrated his attention for well over half a century.

Though the most conspicuous trait of De Vries, throughout life, was his demand for the same concrete specific evidence in genetic research that he had required in his physico-chemical researches, nevertheless his mind was restless. While waiting for experimental results that were slow in coming, therefore, he began to speculate on the philosophical requirements for an hereditary mechanism. The results of his conjectures were brought together in a small volume called Intracellular Pangenesis, issued in 1889. The conception was an outgrowth of Darwin's ideas of pangenesis and of Weismann's *Kontinuität des Keimplasmas* (1885) in many respects; but it more nearly anticipated our modern notions than either. De Vries himself said later that he based his "testing of native plants on the hypothesis of unit characters as deduced from Darwin's Pangenesis." But such credit was rather more than was Darwin's due. De Vries had observed what we now call the results of gene segregation; and it was only natural that a man with chemical training should attribute these phenomena to the action of hereditary units. One may assume, therefore, that his conclusions would not have been different had he been unacquainted with the works of both Darwin and Weismann. He simply assumed reproducible units of heredity within the nuclei of all cells, whose activity was manifested only when they or their products passed into the cytoplasm. Variation was the result of change in either number or quality of the pangenes.

De Vries discovered for himself the ratios exhibited by the selfed progeny of monohybrids, by studying controlled hybrids from such genera as Chelidonium, Datura, Solanum, Veronica, and Zea. To these results he gave the correct interpretation, though the analysis had not the elegant precision of Mendel's paper. Mendel's own forgotten work he rediscovered in 1900 (as at the same time did Correns and von Tschermak) by means of a reference found in L. H. Bailey's book on Plant Breeding (1895). These results were presented to the German Botanical Society under the title "Das Spaltungsgesetz der Bastarde," and to the French Academy of Sciences under the title "Sur la loi de disjonction des hybrides"; and from that date the growth of genetics was rapid.

In 1901–1903 De Vries published his great work, *Die Mutationstheorie*. The first volume was on *Die Entstehung der Arten durch Mutation;* the second volume was *Elementare Bastardlehre*. Much of its substance was afterwards issued in English under the title "Species and varieties, their origin by mutation." Other later books included *Plant Breeding;* comments on the experiments of Nilsson and Burband (1907), *Gruppenweise Artbildung, unter spezieller Berücksichtigung der Gattung Oenothera* (1913). In addition, 189 of his scientific papers up to 1925 were collected in seven volumes containing 4300 pages, under the title "Hugo de Vries: Opera e periodicis collata."

It was not to be expected that the analyses of the numerous genetic problems considered in this tremendous quantity of published work should stand the test of time. The special puzzle presented by the genus Oenothera has been solved along other lines than those originally suggested. But it was the work of De Vries that made solution possible. His contributions were fundamental. Evolutionists to-day do not accept the picture drawn in *Die Mutationstheorie*. The word *mutation* has taken on some rather "undevriesian" connotations. That is what De Vries would want. He was not a static entity. He grew and changed, as science grew and changed. To the end his mind was facile. No one was better pleased than he when a problem he had posed was solved. He was a great thinker, a stimulating leader, a man who radiated ideas and passed them to his fellows. He was a worthy heir to Darwin's mantle. Without his example, the development of genetics would have been delayed for years.

Many honors came to De Vries, particularly in England and the United States. He received the Darwin Medal in 1906, the Vietsch Medal of the Royal Horticultural Society in 1910, and the Gold Medal of the Linnaean Society in 1929. Honorary degrees were conferred upon him by four universities in America and by five universities in Europe. Some three score learned societies counted it an honor to enroll his name. He was elected a foreign honorary member of the American Academy of Arts and Sciences in 1921.

De Vries visited the United States on three occasions. In 1904 he delivered the principal address at the opening of the Station for Experimental Evolution of the Carnegie Institution of Washington. He then proceeded to the University of California, where he gave a course of lectures which did more to stimulate experimental biology in America than had the efforts of any other one man. He lectured at American universities again in 1906, and still again in 1912, when he opened the Rice Institute at Houston, Texas.

In these American trips, De Vries endeared himself to every biologist with whom he came in contact. He was a lovable man, quiet and dignified, but kindly and genial.

E. M. East.

ROLAND BURRAGE DIXON (1875–1934)

Fellow in Class IV, Section 2, 1910

Roland Burrage Dixon, the senior member of the Division of Anthropology of Harvard University, died at his home in Harvard, Massachusetts, on the nineteenth of December, 1934. Dr. Dixon was born at Worcester, Massachusetts, on November 6, 1875. He graduated from Harvard College in 1897 and three years later took his doctorate in Anthropology at that institution. From his senior year in college to his death Dixon taught Anthropology to Harvard students and to graduates of institutions in many parts of the world who came to share in his enormous store of erudition. Before Dixon's time instruction in Anthropology at Harvard was somewhat haphazard and unsystematic. Courses were attended casually by some undergraduates and assiduously by an occasional graduate student with professional ambition. Dixon set himself to organize a complete anthropological curriculum and to gather together a teaching staff which would be competent to give advanced instruction and to direct research in all specialties of the science. He built up at Harvard a school for the training of professional anthropologists which was worthy of the academic traditions of the University and from which have gone out many able workers in the field of American Anthropology.

Dixon was passionately devoted to an ideal of anthropological scholarship which insisted upon a thorough factual and theoretical knowledge of all aspects of the science as a foundation upon which to specialize. Consequently every aspirant for the Harvard doctorate in Anthropology was forced to submit himself to a rigorous course of training in subjects other than those in which he happened to be particularly interested. It mattered not how brilliant a man might be in Physical Anthropology, for instance; he nevertheless had to pass a severe examination in Archaeology and Ethnology, before he could offer a thesis in his specialty. By his uncompromising insistence upon this standard Dixon either corrected or discouraged lop-sided enthusiasts and made the Harvard doctorate one of the coveted and respected degrees in Anthropology.

As a teacher, Dixon was always edifying, often stimulating, but rarely entertaining. Each lecture hour was a sixty minute sprint through a huge territory of carefully organized knowledge, which left most of his auditors who held the pace mentally exhausted, or, at best, doubled up with writer's cramp. Yet the graduate student who survived these factual Marathons, found himself equipped with a thesaurus of anthropological knowledge which he could utilize throughout his entire professional career, both as a solid background for his own research and as a powerful weapon against less substantially educated adversaries. Dixon was an admirable director of the research of advanced students. In this capacity he was compelling, exacting, and critical. He gave to each research student a full hour of his time every week, during which the latter presented the results of his work, and the former analyzed, discussed, probed, diagnosed, and administered, if, necessary, a mental cathartic. Dixon's doses were never graduated according to the age or capacity of the patient; he gave the same strong and copious medicine to all. He never tempered the wind to the shorn lamb.

Yet Dixon was a just and by no means ruthless man. His fairness and sound judgement were never more evident than in the inquisition of doctoral examinations. His verdict upon a candidate generally carried the jury of his colleagues, because he was absolutely impersonal, totally honest, and completely dominated by his very clear conception of the requisites of professional Anthropology.

One of Dixon's most substantial achievements is the anthropological library of the Peabody Museum. The unique feature of this collection is the completeness of its catalogue. Full sets of virtually all anthropological periodicals are indexed not only by year and by volume, as in most other libraries, but by individual authors and by subjects. Thus if an investigator wishes to obtain a bibliography on, for example, totemism, he will find under that heading in the subject catalogue nearly all books and articles on the subject found in anthropological literature. This cataloguing system, devised by Dixon and developed under his supervision, has made the Peabody Museum Library one of the most useful collections of its kind in the world. The colossal task of keeping up this cataloguing system upon a very scanty budget and of selecting volumes for purchase, as well as arranging exchanges, absorbed a great deal of the time and energy of Dixon for more than thirty years. It was one of those thankless jobs, which no one else was willing to undertake, but which Dixon performed with characteristic thoroughness and efficiency, thus creating for students of Anthropology an unrivalled instrument of research.

Dixon produced, of course, a formidable list of technical papers on anthropological subjects, all scholarly and for the most part rather uninteresting. But in 1923 he published his *Racial History of Man*, which was one of the most venturesome and original forays into the field of Physical Anthropology (not his own field) ever undertaken by a recognized authority in the general subject. It was, in fact, a sort of single-handed "Charge of the Light Brigade." Certainly, cannon to right of him, cannon to left of him, cannon in front of him (as well as a few behind) volleyed and thundered. Here is not the place to expound or to dissect Dixon's superlatively original scheme of classifying mankind on the basis of combinations of certain cranial indices in individuals. It called down upon him almost universal condemnation; it was as permeable as a sieve; and yet when he had passed through this sieve, with his inimitable industry, virtually all recorded crania from every region of the world, he produced for the first time an intelligible and consistent interpretation of the migrations of peoples and mixtures of strains which have brought about the present distribution of the world's population. With his home-made pop-gun he scored more bull's eyes than have all the anthropological artillerymen with their high-power, precision pieces. Of course he missed the mark entirely a great many times, but he succeeded in writing what I believe to be the most stimulating and provocative work on Anthropology which has appeared since Darwin's *Descent of Man.* The *Racial History of Man* will be read (and probably cursed) for many years after the acclamations of more conventional anthropological treatises have died away.

As befits the anthropologist, Roland Dixon at various times wandered up and down in the far parts of the earth studying primitive peoples. Nevertheless he was singularly uninterested in his fellow human beings, although he spent his life studying them. He was preoccupied rather with their cultures and the probable methods of cultural diffusion. His real love was Nature and out-of-doors life. He spent many summers camping and tramping with one or another of his few intimate friends. He was so much the complete bachelor that one was inclined to regard his state as the manifestation of a congenital aversion for the other sex. Nor did he cultivate many close friendships among his fellow males. He was courteous, kindly, but withdrawn. Probably only two or three persons were really permitted to know this lonely scholar—certainly none of his departmental colleagues, although he was on terms of easy familiarity with them all and enjoyed their confidence and respect.

Here then was a shy and unpretentious scientist who in some respects approximated, if not achieved, greatness. At a minimum estimate he was one of the most useful and influential anthropologists of his generation, a teacher and investigator of whom his university and his associates were fittingly proud. For the last three years of his life, he pursued his work in the torture of a wasting disease, the very existence of which he refused to admit, perhaps because he could not endure to be the object of expressions of sympathy. He dragged himself to his lectures and performed his appointed duties until he collapsed in the Peabody Museum. Thus passed Roland Burrage Dixon, whom no single anthropologist can replace.

E. A. HOOTON.

LOUIS DOLLO (1857–1931)

Foreign Honorary Member in Class II, Section 3, 1928

Louis Dollo was born at Lille, in Flanders, the 7 December 1857 and died, after a long illness, at Uccle, near Brussels, the 19 April 1931.

Dollo studied at the University of Lille, 1873–1877, where he graduated as a civil engineer. He pursued at the university studies in geology and zoology and for many years came under the influence of the brilliant anatomist, Paul Albrecht, who was a student of Gegenhaur's.

After a brief period in industrial work Dollo, under the influence of Kowalewsky, became a palaeontologist. Following his inclinations, in 1882, Dollo was appointed assistant in the Royal Museum of Natural History in Brussels. Later, in 1891, he was appointed conservator and he remained at the Brussels Museum occupied with research and museum work until his retirement in 1925, covering a period of 47 years. In addition to work at the Museum, in 1909 he became Professor of Palaeontology at the University of Brussels.

Dollo came to the Brussels Museum to study and work on the great collection of fossil reptiles for which that museum is famous; later he took over all the fossil vertebrates. He built up an osteological collection for comparative study. He supervised the preparation and mounting of many specimens in the Brussels Museum including the superb series of Iguanodons from Bernissart which is one of the most splendid displays of any Museum in the world. By his masterly analysis of Mesozoic and Tertiary reptiles he rendered the museum signal service. He arranged and labeled the unique collection of fossil vertebrates in the New Brussels Museum, which was opened in 1905, and prepared a general guide book to the recent and fossil vertebrates in the museum.

Dollo as an investigator will always be remembered for his numerous valuable contributions to our knowledge of fossil vertebrates. While his work was primarily on the fossil reptiles of Belgium, especially Mososaurs and Iguanodons, he published numerous papers on other reptiles, also on fossil fishes, birds and mammals, as well as on many groups of fossil invertebrates. After the voyage of the Belgica he published as well on Antarctic deep-sea fishes.

Dollo belonged to the great school of morphologists of the last century, and the structure and anatomical relations of his material were constantly in his mind. He urged that palaeontology should be considered as a biological study, rather than be associated with geology. He was essentially philosophical in his work and published much on evolution. He established the general principle that in evolution an animal never returns to its former state, even if in circumstances identical with those through which it has passed. He described this as the law of irreversability of evolution and it is sometimes called Dollo's law. He also urged the importance of "Ethology" or the relation of organisms to their surroundings. In addition to his technical scientific work Dollo was deeply interested in the study of languages, and in biochemistry, and he was a lover of music.

An appreciative notice of Dr. Dollo was published in *Nature*, 1931, vol. 128, p. 57 and another in *Bull. Mus. Royale d'Hist. Nat. de Belgique*, 1933, vol. 9, no. 1. In this last an extensive bibliography of his writings is given, including some 475 titles. Dr. Dollo was deeply admired and received wide recognition for his work. He was a foreign member of the Linnean, Geological and Zoological Societies of London, and was awarded the Murchison Medal of the Geological Society. He was also an honorary Sc.D. of Cambridge, and a corresponding member of the Academies of Science of Berlin, Munich, and New York.

ROBERT T. JACKSON.

WILLIAM DUANE (1872–1935)

Fellow in Class I, Section 2, 1914

William Duane came of distinguished ancestry. He was a descendant in the fifth generation from Benjamin Franklin, the family line running as follows:

Sarah, a daughter of Franklin, married Richard Bache, a native of England. The sixth child of this pair, Deborah, married William

John Duane. William Duane, the oldest of nine children of this union, married Louisa Brooks. From this marriage there were two children, a son and a daughter; the son, Charles William, was rector of St. Andrew's Church in West Philadelphia and he was the father of William Duane, the subject of this biographical note. From Franklin down the family lived in or near Philadelphia. From Richard and Sarah Bache was descended also, in the second generation, Alexander Dallas Bache, Superintendent of the United States Coast Survey for many years and one of the founders of the National Academy of Sciences. William John Duane was the son of the William Duane who, as editor of the Philadelphia *Aurora*, was influential in bringing on the War of 1812. William John Duane was Secretary of the Treasury under President Jackson but resigned or was dismissed from his office after refusing to remove the government deposits from the United States Bank at the order of the President.

Our William Duane was born in Philadelphia February 17, 1872. He received the degree of A.B. from the University of Pennsylvania in 1892 and from Harvard a year later. After two years as an assistant in physics at Harvard he went to Germany as holder of the Tyndall Fellowship, and in 1897 he was given the degree of Ph.D. at Berlin. He was Professor of Physics at the University of Colorado from 1898 to 1907, was engaged in research at the Curie Radium Laboratory in Paris from 1908 to 1913, became Assistant Professor of Physics and Research Fellow of the Cancer Commission at Harvard in 1913, and Professor of Bio-Physics in 1917, a title which he held till his death, though because of illness he was emeritus during the last year of his life.

In his early years at Harvard he was engaged with Professor Trowbridge in a research on the velocity of electric waves along wires. His thesis for the doctorate was on a subject in physical chemistry, a study of thermo-electrolytic action. During his professorship at the University of Colorado he probably had little opportunity for research. His experimental work in Paris produced several papers which were published in the *Comptes Rendus* of the Académie des Sciences during the years 1909–1912, all under the general heading of radioactivity.

It does not appear that during his residence in Paris he had given any especial attention to the therapeutic value of the various new found "rays," but his studies there had made him proficient in the technique of producing and directing such rays, and his native ability enabled him speedily to adapt his attainments to the requirements of his new professorship, probably the first of its kind in America. He soon became an authority on the means for applying "radium emanation," and later X-rays, to the treatment of cancerous growths.

His duties at the Medical School did not, however, occupy all of his time or energy, and he continued at the Jefferson Laboratory his investigations of the purely physical or chemical properties and effects of the new forms of radiation, especially those of the X-rays. He published, sometimes in cooperation with student assistants, many papers descriptive of his experimental methods and the results obtained. A considerable number of these papers dealt with the medical aspects of his work.

In 1922 he received two prizes in recognition of the value of his achievements. One of these, the Leonard prize, came from the American Roentgen-Ray Society, which appears to have been an association of those making a medical use of X-rays and to be no longer active. Concerning the other prize, the *New York Times* of April 9, 1922, states that Professor Duane "has been awarded the John Scott medal and certificate, with a premium of $800, by the Board of Directors of City Trusts of Philadelphia for his researches in radio-activity and X-rays." It adds, "This award is made annually for scientific achievement in accordance with the terms of a bequest made over a century ago by John Scott. Last year the winner was Mme. Curie." Apparently the medical side of Duane's activities was given especial attention as a ground for this award.

In 1923 he was given the Comstock prize of the National Academy of Sciences. This prize, awarded once in five years, is a very great honor and in addition it brings to its recipient a substantial sum of money, approximately the accumulated income of a $12,000 fund.

He was a member of the National Academy of Sciences, of the American Philosophical Society, and of many other associations, scientific or medical.

He married in 1899 Caroline Elise Ravenel of Charleston, South Carolina. Of this union there have been four children, William, Arthur Ravenel (now deceased), John, and Margaretta.

Duane was in seriously failing health and comparatively inactive for some years before his death. His most noticeable characteristic was quietness. He never raised his voice, never seemed excited or hurried. He was quietly courteous, quietly friendly, quietly efficient. He was a lovable man and a worthy descendant of his famous ancestors.

EDWIN H. HALL.

EDWARD WALDO EMERSON (1844–1930)

Fellow in Class III, Section 4, 1917

Edward Waldo Emerson, born on July 10, 1844 in Concord, was the youngest of the four children of Ralph Waldo Emerson. Like his mother, young Edward was not physically robust. The oldest son died when very young. The other three children grew up in the Concord of the latter half of the nineteenth century. Their father, who was forty-one years old when Edward was born and who died when his son was thirty-seven, lived at home most of the time. When he was away on his lecturing tours Mr. Thoreau, then a young man, sometimes lived in the Emerson house and occupied the position of elder brother or uncle to the children, and gained their affection by his remarkable personality and his great kindness to them. They also knew the Hawthornes, the Alcotts, and the other notable people of Concord.

At school and college young Edward was studious and intelligent, but not brilliant. A strong love for literature, poetry, and art distinguished him, and from his youth onwards the knights and the chivalry of the middle ages fascinated him. In fact he was interested in soldiers of all periods and had himself a strong military instinct. Doubtless the knightly qualities in his own character—his gentleness and courage—owed something to that life-long interest. He not only learned to ride early and was a good horseman all his life, but was also at home on the river in swimming, skating, rowing, and later in life in canoeing.

In July, 1861, he passed his examinations for Harvard and entered college in the autumn at the age of 17. But at the end of seven weeks, failing health forced him to leave college and return to Concord, where he spent the winter at home. An out-door life with a surveying party combined with woodchopping helped to put him on his feet again. In May 1862, to build up his health, he took the train to Omaha and, accompanied by a doctor friend, rode over the Emigrant Trail across the continent. He made the last part of the journey by stage coach and returned by way of Panama. The next year with renewed strength he re-entered Harvard, in the Class of 1866, and after the usual four years of college life was chosen class poet at graduation.

Probably the greatest disappointment of his life was his failure to get into the Northern Army in the Civil War. Though eager to go, his family and friends opposed his offering himself because they felt that his health was too delicate; their judgement was borne out by the fact that during the War he was twice drafted and twice rejected by the medical officers for physical unfitness.

After graduating from Harvard he went out to Burlington, Iowa, and worked as a clerk in the office of the Burlington and Missouri Railroad; but after a while his eyes troubled him and caused his return to Concord. Soon afterwards, ill health, so frequently his enemy in those early years, again attacked him, this time in the form of a serious illness with complications which, together with a long convalescence, held him back once more. But out-of-door life and work in a vineyard so restored his health that he was able to enter the Harvard Medical School in the autumn of 1868, and after nearly six years of study there and in Berlin and London, he received his M.D. degree from Harvard in 1874. He began practice as the assistant of Dr. Josiah Bartlett of Concord. After Dr. Bartlett retired, Dr. Emerson became the country doctor of Concord, with a scattered practice also in Bedford, Lincoln, Acton, and other nearby towns; visiting his patients on horseback or in a buggy, and in winter by sleigh.

In September, 1874, he married Annie Shepard Keyes of Concord, and with her began a long and happy married life.

Their first three children, all sons, died when very young. The four remaining children grew up and three of them married, but only one, his youngest son Raymond, has survived the father.

Dr. Emerson's intimate friends knew that he wished to be an artist rather than a physician, but he chose medicine as a career at the wish of his father, partly because it was felt to be necessary that he should earn his living, and in those days the chance of earning a living by art was very slight.

Many stories could be told of Dr. Emerson's life as a country physician, and of his gallantry and self-sacrifice under all circumstances. Once, at night, his horse fell with him and pinned him in a snowdrift with a broken leg and no one near, but he managed to drag himself free, mount again, and get home. He was decidedly successful as a country family doctor, and won the love and respect of his patients.

In 1882, when his father died, he discontinued his practice of medicine except as a consulting physician, and for a while devoted his time principally to the study of art. He began by working with his classmate, Frederick Crowninshield, and studied at the School of the Museum of Fine Arts in Boston, and in the winter of 1885–86 was appointed instructor in Art Anatomy in that school, a position which he held for twenty years.

Dr. Emerson was a good draughtsman and understood well both human and animal anatomy, and further had a strong love of the poetry which he saw in the visible world and which gave him his chief inspiration to paint; but partly perhaps because his inexorable conscience would not let him paint when it was his duty to study—in school, college, or medical school—and later to practice medicine, he never achieved distinction as an artist. In the spring of 1896 he held his only exhibition of paintings. It was moderately successful and, though most of the pictures were loans, some of those that were not thus reserved were sold.

His gift as a writer and lecturer brought him greater reputation. He was frequently asked to lecture in the West as well as in New England. In 1882 he was made an honorary member of the Phi Beta Kappa, and fifteen years later was invited to read a poem at the June meeting of the Harvard chapter. In 1882, not long before he gave up the practice of medicine, he read before a Medical Society a paper on "The Man as Doctor." Fifty years later, Dr. Henry P. Walcott said that that lecture was a masterpiece and produced a great impression on the doctors of that day.

Dr. Emerson also wrote various other articles which have been collected since his death and published by his son Raymond under the title of "Essays, Addresses, and Poems." The collection includes "The Chaplain of the Revolution," the subject of which was his great grandfather, who lost his life in the Revolutionary War, and contains also "A History of the Gift of Painless Surgery," published in the "Atlantic Monthly" in 1896, in which Dr. Emerson tells the story of the discovery of the use of ether for medical purposes by his mother's brother, Dr. Charles T. Jackson, who taught it to Dr. Morton and thus made him famous for first demonstrating the discovery at the Massachusetts General Hospital.

Dr. Emerson also wrote two or three books, one entitled "Emerson in Concord" which gives the picture of his father's life in Concord as a neighbor and friend, and so supplements Mr. Cabot's more elaborate work which deals with the life of the elder Emerson as a philosopher and poet. He wrote also a life of Colonel Charles Russell Lowell, the gallant soldier who lost his life in the Civil War Battle of Cedar Creek.

Among his other writings were: additional essays about his father, a short account of his personal reminiscences of Henry Thoreau, and the life of Judge Ebenezer Rockwood Hoar in collaboration with Mr. Moorfield Storey.

Dr. Emerson's most important work was the editing of his father's writings and journals. Mr. James Eliot Cabot had helped Ralph Waldo Emerson during his lifetime to bring forth the first complete edition of his essays and poems. In 1903, some twenty years later, Dr. Edward Emerson brought out the Centenary Edition of his father's works, with carefully written notes, and during the next ten or twelve years, with the assistance of his nephew, Waldo Emerson Forbes, he brought forth the ten volume edition of his father's journals, a great labor. His last work was the book entitled "The Early Years of the Saturday Club," an organization to which both he and his father belonged. His history of the coming together of that well known group of writers and other distinguished men in Boston in 1857 and the years following, included not only short biographical sketches by himself but also a few by other members of the Club.

In all these various publications, notably of his father's works, he showed himself to be conspicuous for good taste and sound judgement and for his ability to make pithy notes and comments on the text.

Most of his married life was spent in Concord. As a public-spirited citizen, he cheerfully took his part in the civic work of the town. He served faithfully on the School, Cemetery, and Library Committees, was chairman of the board of health, and also held positions in connection with State Institutions. In 1889 he was elected a member of the Saturday Club and in 1917 became a member of the American Academy of Arts and Sciences. During the Great War he joined the

"Concord Minute Men," a purely voluntary organization which was established as a part of the preparedness movement. He drilled in the State Armory with them, though he was then seventy-two years old.

He visited Europe twice after his marriage; for nearly two years in 1893 with his whole family, and later with his wife and eldest daughter and some friends in 1905. As he grew older the South proved a pleasant retreat from the severity of the New England winters. He died in Concord on January 27, 1930 at the age of eighty-five.

His whole life was characterized by great gentleness, consideration and generosity, combined with an absolutely unflinching devotion to duty, and a courage that had never given way. His innate refinement and his enthusiasm for what was beautiful in literature and art, both romantic and classic, were conspicuous. His father had said "Character is greater than intellect." When, towards the end, Dr. Emerson's mind and body began to weaken noticeably, his character, which had always shown a granite-like strength, remained. During those last protected days in the quiet town of Concord, it was the courtesy and consideration rather than the strength that was visible.

EDWARD W. FORBES.

JESSE WALTER FEWKES (1850–1930)

Fellow in Class III, Section 2, 1887

Jesse Walter Fewkes, son of Jesse and Susan Emeline (Jewett) Fewkes, was born in Newton, Massachusetts on November 14, 1850 and died in Washington, D. C. on May 31, 1930. He was graduated from Harvard College in 1875 with membership in Phi Beta Kappa. During his undergraduate career he was a member of the Agassiz school at Penikese Island. His work with Agassiz in the Graduate School led to the Master's and Doctor's degrees. For three years he studied zoölogy at Leipzig and under the Harris Fellowship spent several months at Naples and Villa France perfecting himself as a marine zoölogist. An appointment as assistant in the Museum of Comparative Zoölogy at Harvard followed his European training.

Paralleling the history of his life-long friend and colleague, Frederic Ward Putnam, his interests turned from zoölogy to American archaeology and ethnology. In 1889, under the patronage of Mrs. Mary

Hemenway and the Peabody Museum, he began his first work in the Southwest at Zuñi Pueblo, New Mexico. He was the first to record by phonograph Indian songs. The ceremonials of the Pueblo tribes, more especially the Smoke Dance, attracted him. This led to a study of the mythology and the traditions of the Hopi Indians and, pushing backward in time, the archaeology of the Southwest became his main interest.

From the time of his connection with the Bureau of American Ethnology at Washington in 1895 until almost up to the time of his death he was continuously engaged in excavations in the Southwest. He became especially interested in the pottery designs and their interpretations. The extensive and documented collections in the United States National Museum bear witness to this long-continued investigation. His repairs to the famous Mesa Verde and Casa Grande ruins will forever be monuments to his activity in the preservation of American antiquities.

Excavations in the West Indies, Porto Rico and the Lower Antilles, and explorations along the Gulf Coast of Mexico were followed by important papers on these practically virgin fields. In 1918 he was appointed Chief of the Bureau of Ethnology.

Dr. Fewkes was the recipient of many honors, among them a Knighthood in the Royal Order of Isabella la Catolica from Spain, the gold medal "Litteris et artibus" from Sweden, an LL.D. from the University of Arizona, and membership in the American Academy of Arts and Sciences and the National Academy of Sciences.

His career as a marine biologist is told in sixty-nine entries in his *bibliography, and as an anthropologist in a far greater number of* important articles and memoirs.

Fewkes was a natural historian in the best sense of the word. His broad interests served him well in the varied approaches to anthropological problems. However, to the newer techniques of archaeology and of anthropology he could never quite adjust himself. Nevertheless, his work will always stand as the first basic attempt to understand the prehistory and the history of the peoples of our southwestern deserts.

ALFRED M. TOZZER.

JOHN GALSWORTHY (1867–1933)

Foreign Honorary Member in Class IV, Section 4, 1931

John Galsworthy, who was elected a Foreign Honorary Member of the Academy on May 13, 1931, died January 31, 1933.

He was born in 1867, of an old Devonshire family, went from Harrow to Oxford, studied law and travelled. But chiefly he wrote, from 1897, when his first work appeared, under a pseudonym, until *Over the River* closed the great Forsyte series in 1933. The resulting body of novels, plays, short stories, sketches, poems, and letters will not soon cease to inspire all good workmen, whatever may be their special calling. For all that he did and was Galsworthy deserved and received many honors, though he was not able to accept all the distinctions that were offered. Honorary degrees came to him from St. Andrews, Manchester, Dublin, Sheffield, Oxford, and Princeton; the O. M. was awarded him in 1929 "for services to literature and the drama." The Nobel Prize was also awarded him, but ill health prevented his going to Stockholm to receive it. He declined knighthood in 1918.

Galsworthy's aim—characteristically put by him in the third person—was simple, exacting, and appropriate: he wished "to present truth as he sees it, and gripping with it his readers or his audience, to produce in them a sort of mental and moral ferment, whereby vision may be enlarged, imagination livened, and understanding promoted." This aim Galsworthy was able to realize because in him great artistic gifts were joined with a remarkable endowment and balance of human qualities.

The justice which presides over his work has more than a little that is Greek about it: "all are bound to their own natures, and what a man has most desired shall in the end enslave him." Thus his plots seem to unroll without the author's manipulation, always in the direction of a "doom" which is strangely inevitable on account of the skill with which it is made to seem the negative of the virtues punctiliously granted to each class. The art is quite marvellous with which, as from a chorus, public opinion is made to surround the central action: "Society stands to the modern individual as the gods and other elemental forces stood to the individual Greek."

But in Galsworthy justice is constantly balanced by sympathy.

His hatred of cruelty is intense: "of all attributes of the human creature," he says, "cruelty is to me the most abhorrent." At the end of *Swan Song* he can think of nothing more poignant to compare Fleur with, after her father's death and her terrible remorse, than a bird that "had been shot with both barrels, and still lived; no one with any sporting instinct could have hurt it further. Nothing for it," thinks the wronged but deeply chivalrous Michael, "but to pick her up and mend the wings as best he could." A subtler form of pity, shading off into a luminous irony, runs through his depiction of such people as the Forsytes, the Carádocs, and the Pendyces. This kind of pity is so far above mere partisanship that it can embrace two opposed characters or social systems at once. It makes the feeling of the others toward De Levis in *Loyalties* seem snobbish yet difficult wholly to avoid. It nicely qualifies its approval of Courtier (in *The Patrician*) and its distaste for the rigidity of Miltoun. "Human nature has room for both and a good deal besides."

Galsworthy was intensely English: witness among a thousand passages, the feeling for one's own part of the land in "Devon for Me!" and in the final pages of *Over the River*. Therefore he was, usually, very reserved: witness his statement that he habitually creates "characters who have feelings that they cannot express." Yet the line in "Donkeys" where God's creation of these patient beasts is described as "One of the best of His numerous chores" is not, merely because its humor happens to be of the sort that we sometimes call American, any the less perfect as an expression, on one of its sides, of his extraordinarily well rounded nature.

The authenticity and significance of Galsworthy's people can perhaps be traced, in part, to the fact that they do not always seem wholly individual. In many of his sketches, especially, we meet them as type-studies, not yet ready to take a living part in novel or play. That some of Galsworthy's people seem not to have got quite far enough from this original state is perhaps their "doom." Yet he would probably reply—and perhaps rightly—that our significance, if we have any, arises to some extent from the fact that we are all less individual than we imagine ourselves to be. For he wrote of one of his characters: "When he met himself about the town (which hourly happened) he had no knowledge that it was himself; on the contrary he looked on himself as specially designed, finding most other people 'rather funny'." In the great gallery of his portraits, therefore, these studies of types and classes, though sometimes weighed down by their responsibility of representing so many besides themselves, do tend to document Galsworthy's best work, even if they are not quite a part of it. They show us how he labored to bring his best characters into a life the completeness of which requires some thought of their representative value as well as of their individuality.

It has often been pointed out that John Galsworthy, like his father before him, was himself a bit of a Forsyte. Obviously, or he could not so remarkably have done the Forsytes both from the outside and from within. But so are we all, all Forsytes, in our several ways. "As surely as a dog will bark at a brass band, so will the essential Soames in human nature ever rise up uneasily against the dissolution which hovers round the folds of ownership." By this fact of their universality, together with the equally certain fact that they are solidly planted, with their houses and their dogs and their flowers, as well as their prisons and their slums, in an England which a great writer loves yet wished to better, these books, at this short distance from them, seem extraordinarily well fitted to endure.

CHESTER N. GREENOUGH.

KARL FRIEDRICH GELDNER (1852–1929)

Foreign Honorary Member in Class III, Section 2, 1925

Karl Friedrich Geldner was born December 17, 1852, at Saalfeld in Thüringen, and died February 5, 1929, at Marburg.

He began the study of Sanskrit and Avestan at Leipzig in 1871 with Brockhaus and Windisch. In 1872 he went to Tübingen, where the great Sanskritist Roth had such a deep influence on him that he remained there until he had completed his studies in 1875. He stayed in Tübingen until 1887, when he went to Halle.

Most of his early published works dealt with the Avesta. Between 1875 and 1895 he was much occupied with Avestan studies and with the preparation of a great critical edition of the Avesta. This is still the standard edition.

At Halle, where he was associated with Pischel, his interests turned more and more toward the Rig Veda. Between 1889 and 1901 he and

Pischel published three volumes of *Vedische Studien*, which subjected Roth's method of interpretation to severe criticism and gave a new direction to Vedic studies. The Rig Veda was not to be explained, as Roth had explained it, as a monument of Indo-Germanic antiquity, but as a work of Indian literature. It was to be explained from itself with the help of later Sanskrit literature and the native Indian tradition of Vedic commentators. It is significant, however, that continued study led him to place much less reliance on the native commentators than he did in the *Vedische Studien.*

In 1890 he went to Berlin as *ausserordentlicher* Professor, and in 1907 to Marburg as *Ordinarius.* He retired as Emeritus in 1921.

In 1908 he contributed to Bertholet's *Religionsgeschictliches Lesebuch* two superb anthologies, *Vedismus und Brahmanisnus* and *Die Zoroastrische Religion.*

His *Rigveda in Auswahl* (1907–1909) was a preliminary to his greatest work, a complete translation of the Rig Veda. The first volume of this was published in 1923; the second and third volumes, and the first volume in a revised form, are now in course of publication in the Harvard Oriental Series.

Geldner concentrated his life's work with undivided attention to the study of the earliest literary documents of Iran and India, the Avesta and the Rig Veda. From 1887 he turned with greater and greater enthusiasm to the Rig Veda, but regarded his edition of the Avesta as a duty which had to be fulfilled. Geldner was always a philologist. His aim was to edit, translate, and explain his texts by every means within his reach, but he did not extend his work to a wider general study of religious, philosophical, historical and cultural problems. As a philologist he concentrated on two great texts and allowed no smaller interests to interfere with his work on them. Of one he made the standard edition; of the other he made the most significant translation which has yet been produced.

WALTER E. CLARK.

FRANK AUSTIN GOOCH[1] (1852–1929)

Fellow in Class I, Section 3, 1879

In the references given can be found details in regard to the life and work of Professor Gooch. In the memoir by Professor VanName there are a number of interesting quotations from a story of his adventures at home and abroad written by Professor Gooch particularly for his two young grand-children.

Frank Austin Gooch was born in Watertown, Mass. on May 2, 1852, and died in New Haven August 12, 1929. At the age of sixteen he entered Harvard College and was awarded the degree of A.B. in 1872 with highest honors in physics and chemistry. He became an assistant to Professor Josiah Cooke, who inspired in him a keen interest in mineralogy. Several visits were made to Europe to study and work in this field. He returned to Harvard University, received his Ph.D. in 1877, and then went to Copenhagen to work with Julius Thomsen in thermochemistry. He returned to accept an opportunity to collaborate with Professor Wolcott Gibbs in the study of the complex inorganic acids. It was this work which determined his future career and led to his becoming a leader in the development of analytical chemistry. His informal autobiography contains this sentence in regard to the crucible known by his name—"It was during this period that I described in a paper a device which has proved to be of such general utility in analysis that, dubbed by the craft with my surname (usually reduced to the level of a common noun) it has found its way into the Standard Dictionary (of the English language) dragging me along with it."

In 1886 F. A. Gooch took up his work as Professor of Chemistry in Yale College. He reorganized the instruction, built a new laboratory, and developed a strong graduate school in chemistry. He was active in research, and solved many difficult problems in analytical chemistry. He introduced important new methods in the volumetric and electrochemical methods of analysis. He was elected to membership in many learned societies and won a permanent place in American Chemistry.

James F. Norris.

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[1] References: Biographical Memoir of Frank Austin Gooch 1852–1929. By Ralph G. VanName. National Academy of Sciences. Vol. XVI. American Contemporaries. By Philip E. Browning. Industrial and Engineering Chemistry XV, 1088 (1923). Obituary, American Journal of Science, 5th Series, *18*, 539 (1929).

MORRIS GRAY (1856–1931)

Fellow in Class III, Section 4, 1918

Morris Gray was born in Boston, March 7, 1856, the son of Francis H. and H. Regina (Shober) Gray. He was graduated from Harvard College in 1877 and from the Harvard Law School in 1880. In the same year he was admitted to the Bar in Massachusetts, and for the rest of his life was a practising lawyer in Boston. He died January 12, 1931.

As a lawyer Morris Gray displayed the orderly mind and care in regard to details which made him an ideal trustee and manager of large estates. But his associates in the Academy remember him rather as a man of letters, deeply interested in literature and the fine arts. It is significant that, although his first publication was "A Treatise on the Law of Communication by Telegraph," 1885, his later writings include "The City's Voice," a volume of poems published in 1923, "The Real Value of Art," an address delivered at the celebration of the fiftieth anniversary of the Metropolitan Museum of Art, and "The Museum and the Public," made up of selections from his annual reports as President of the Museum of Fine Arts. It is equally significant that the societies with which he was associated besides the American Academy of Arts and Sciences were the American Federation of Art, the Boston Society of Architects, the Boston Society of Arts and Crafts, the Numismatic and Antiquarian Society of Philadelphia, and the Authors' Club of London.

Morris Gray will be best remembered, perhaps, for his long and distinguished service to the Museum of Fine Arts. He was a Trustee of the Museum from 1902 until his death, and President of the Board from 1904 to 1924, a period marked by remarkable growth in the wealth of the Museum's collections and the enlargement of its building. It was during his administration that free concerts were first established at the Museum, and that all fees for admission were abolished.

To those who knew him best it was not so much the wide interests of Morris Gray as the quality of the man himself that made a special appeal. His kindness to younger men even when he was critical, and his consideration for the opinions of others even when they were contrary to his own were among his marked traits. He revealed himself most in his writing; everything he did, even the occasional speech, was carefully thought out and scrupulously revised, and the result was often poetry in prose.

GEORGE H. CHASE.

ADOLF VON HARNACK (1851–1930)

Foreign Honorary Member in Class III, Section 3, 1904

Carl Gustav Adolf von Harnack was born on May 7, 1851, at Dorpat, Esthonia, where his father, Theodosius Harnack, was professor of Theology. His education was at Dorpat and at Leipzig, and at the latter place he became head of the Department of the History of Christianity in 1876. He was Professor at Geissen in 1879, in Marburg from 1886 to 1889, and in Berlin from 1889 to 1924. In 1900 he was made Rector of the University of Berlin, and from 1909 to 1921 he was Director of the Royal Library. In 1914 Kaiser Wilhelm II elevated him to the hereditary nobility of Prussia and at the time of his death he was president of the Kaiser Wilhelm Society for the Advancement of Science, which he had founded. His death occurred in Heidelberg in June, 1930, at the age of 69 years.

It is interesting to note that he followed somewhat in the footsteps of his father and made Christian Theology and the History of Christian Thought his lifelong study. His books and pamphlets are legion—1700, it is said—and the Library of the British Museum has one hundred fifty-two separate titles. His most important work is his *Lehrbuch der Dogmengeschichte* in four volumes (1886–1890), which has passed through many editions and has been widely translated. He devoted his whole life to a continual study of historical and documentary sources of Christianity and is said to have detected many sayings of Christ not included in the New Testament but which have as good authority as those admitted to the canon of the New Testament. One of his ambitions was to reconcile Christianity and modern science. His researches into original sources and early expressions of dogma resulted in such new and vigorous reorganization of ideas of Christian dogma that the effects were felt in both conservative and liberal schools of religious thought. One of his basic theses was that the early Christian faith was positively affected by Greek philosophy and to such an extent that often Greek ideas rather than Christian doctrines found their way into the Christian faith and practices.

At the times when his books appeared severe criticism was aroused against him, and he was drawn into severe and wide controversies. One particular point which he always maintained was that students of Church doctrines should examine their history and substance, and that students of Theology should also maintain a mind open to all facts and new material. Perhaps equal in importance with his specific stands regarding the evolution of Christian dogma was his own attitude, one which he pressed upon his students, of an open mind toward all matters relating to Christian doctrine, dogma, and authority. His books and his pamphlets have circulated widely in this country and he has been considered a high authority in matters of Christian dogma and a fine ideal of honest free thinking.

LEE S. MCCOLLESTER.

OLIVER HEAVISIDE (1850–1925)

Foreign Honorary Member in Class I, Section 2, 1899

Oliver Heaviside, a genius in the field of mathematical physics, was born in London, England, on May 13, 1850. He was the nephew, on his mother's side, of Sir Charles Wheatstone, the eminent British telegraph engineer. One of his brothers—Arthur West Heaviside—was a superintending engineer in the British Post Office Telegraph Department, and a pioneer in radio telegraphy.

After leaving school, Heaviside entered the service of the Great Northern Telegraph Co. at Newcastle-on-Tyne. This company extended telegraph service by cables and land lines to Northern Europe and to the Orient. His interest thus became aroused in electric telegraphy to the study of which he devoted his spare time. By arduous home study, for he never attended college, he developed a remarkable mathematical talent for attacking the numerous unanswered problems of telegraph transmission. He was very shy and retiring by nature, and also suffered from deafness, so that, as time went on, he shunned society more and more. He preferred to live alone, first in London, and subsequently in Torquay, on the south Devonshire coast, living a hermit's life in penury rather than follow a vocation in practical life; because he could devote himself to his beloved applied mathematics. His articles on electrical subjects were communicated mainly to "The Electrician" of London, between 1885 and 1900, and to the "Philosophical Magazine" after 1900. These articles were far above the reach of most electrical engineers of that time. The editors often begged him to simplify his mathematics, but to Heaviside's mind they seemed to be already very simple.

In the course of his studies on the transmission of electric waves over wires, he was able to show that by theory the distributed inductance of telephone lines should be considerably increased. He also suggested inserting inductance coils in the line by experiment. His suggestions in this direction met with little encouragement. In later years, the successful use of inductive loads, inserted at regular distances in such lines, seems to have caused him much disappointment.

As a mathematician he was almost wholly self-educated. He invented methods of his own for dealing with particular problems in electro-physics. He firmly believed that mathematics should be treated as an experimental science, and judged according to its scientific results. For this originality, he suffered some censure at the hands of the classical mathematicians. It is only in recent years that Heaviside's operational calculus has been accepted as orthodox.

Heaviside's collected papers on electrical theory were published in 1892, and subsequent volumes up to 1912. By that time his fame as a mathematical physicist had become well established. He was elected F.R.S. in 1891, and received the Faraday Medal in 1921. He also received a Ph.D. degree from Göttingen University. In America, he was an honorary member of the American Academy of Arts and Sciences, and also of the American Institute of Electrical Engineers.

He contributed very notably to the theory of three-dimensional vectors, electromagnetic inertia, transient phenomena, and wave transmission.

In his later years, he lived entirely alone near Torquay. He had a small pension hardly sufficient for his subsistance, but he resisted the efforts of his friends to increase his income. Very few persons came into contact with him, although he had many scientific admirers. Sir William Preece, long the chief engineer of the British Post Office, used to speak of him as the "veiled prophet."

Heaviside died February 3, 1925, much honored, but personally almost unknown.

A. E. KENNELLY.

WILLIAM COOLIDGE LANE (1859–1931)

Fellow in Class III, Section 4, 1907

William Coolidge Lane was born in Newton, Mass., July 29, 1859, the son of William H. and Caroline M. (Coolidge) Lane. With the exception of a brief interval, his entire active life after graduation from Harvard in 1881 was passed in various capacities in the Harvard College Library. From 1893 to 1898 he was Librarian of the Boston Athenaeum but was called back at the end of this period to become Librarian of the Harvard College Library as successor to Justin Winsor; he held this post for thirty years. Upon his retirement he was awarded an honorary A.M. by Harvard. A bibliography of Lane's writings is included in No. 21 of the *Harvard Library Notes* (August 1928) and a sketch of his life is given in his Fiftieth Anniversary Class Report.

Lane's interest in the technical side of library administration was always very keen and many of his contributions devoted to aspects of this field were printed in the *Library Journal*. At the same time he had strong literary and antiquarian interests. He was one of the leading pillars of the Dante Society throughout his life and was also a member of the Massachusetts Historical Society, the Colonial Society of Massachusetts, and an honorary member of the Literary and Historical Society of Quebec. He was likewise President of the Old Cambridge Shakespeare Association from 1910 to 1931. His penchant was more antiquarian than historical: he did much research into the history of Harvard College, was deeply interested in the Harvard Archives, and was the founder of the Harvard Memorial Society. Among the national organizations in which he was especially active were the American Bibliographical Society, of which he was President (1904–1909), and the American Library Association (President, 1898–1899).

He married Bertha Palmer in 1902 and is survived by his widow and two daughters, Miss Margaret Lane and Mrs. Milton E. Lord. He retired from the post of Librarian of the Harvard College Library on September 1, 1928, and died three years later of a heart ailment on March 18, 1931.

Quiet, unassuming and retiring, Lane carried out faithfully and intelligently a task of great importance in technically organizing the

Harvard College Library, which quadrupled itself during his term of office.

ROBERT P. BLAKE.

HENRY ROSEMAN LANG (1853–1934)

Fellow in Class IV, Section 3, 1915

Henry Roseman Lang, who was elected a Fellow of the American Academy of Arts and Sciences in Class IV, Section 3, died on July 25, 1934, at New Haven, Connecticut. He was born at Wartau in the Canton of St. Gall, Switzerland, on September 22, 1853. In 1874 he graduated from the Gymnasium at Zurich and soon thereafter he began his career as a teacher in the United States. From 1878 to 1884 he was Professor of Modern Languages in the Peabody Normal College at Nashville, Tennessee. Thence he passed to other schools, but he interrupted ere long his labors as an instructor to prepare himself for the degree of Doctor of Philosophy, which he received at the University of Strasbourg in 1892. He returned immediately to the United States and entered at once into the Department of Romance Languages and Literatures at Yale University. There he was active for forty-two years, and he was the incumbent of the Barge Professorship of Romance Languages from 1896 to the date of his retirement in 1922. As Professor Emeritus from 1922 to the time of his death he continued in close touch with Yale University.

On August 29, 1901, Lang married Alice Hubbard Derby. Their happy union lasted until she passed away on July 19, 1928. Her memory will be kept alive at Yale by the Alice Derby Lang Memorial Prize which he established in her honor; by his will he has provided for further memorials for her at Yale and at Smith College.

In the classroom Professor Lang was noted for his accurate control of all the subjects with which he dealt, and he gained the abiding good will of his students. As a man of research and a productive scholar, he obtained world-wide recognition, particularly for his investigations in the fields of early Portuguese and early Spanish literature. There will long remain as monuments of learning his edition of the poems of King Denis of Portugual (*Liederbuch des Königs D. Denis*, 1894) and his edition of a very important collection of Gallician poems and songs (*Cancionero Gallego-Castelhano*, 1902). Outstanding among his many contributions to Spanish philological research are his *Contributions to the Restoration of the Poema del Cid* (in *La Revue hispanique*) and the study which he prefaced to his reproduction of the *Cancionero de Baena* (1926). He was fearless in combating what he regarded as the erroneous doctrines of other scholars, but he was uniformly courteous in the manner in which he presented his arguments in rebuttal of theirs. Those who had the privilege of enjoying his personal friendship have reason to lament his passing, even though his span of life was a long one.

In Portugal his merits were acknowledged by his election as a Corresponding Member of the Portuguese Academy of Science and, while the land was still a kingdom, by the conferment upon him of a Knight Commandership in the Portuguese Order of Santiago; as was fitting, he was made a Corresponding Member of the Spanish Academy at Madrid.

J. D. M. Ford.

EDWIN RAY LANKESTER (1847–1929)

Foreign Honorary Member in Class II, Section 3, 1902

Sir E. Ray Lankester was one of the dominant figures of biology during the latter part of the nineteenth century. As physiology came to prevail over morphology in the twentieth century his influence was less felt.

Professor Lankester was born in London on May 15, 1847. He died on August 15, 1929.

His father was a well-known physician, a Fellow of the Royal Society, and for many years editor of the Quarterly Journal of Microscopical Science.

He was given a classical education at St. Paul's School in London, and entered Cambridge University at the age of seventeen. Two years later, attracted by the zoologist Rolleston, he transferred to Oxford, entering Christ Church College as a junior student. After graduating with first-class honors in natural science, as Radcliffe Travelling Fellow he studied marine zoology at the Naples Biological Station. On his return to England he taught successively at Oxford, London, and Edinburgh. In 1890 he succeeded Mosely as Linacre Professor of Comparative Anatomy at Oxford. In 1898 he became Director of the Natural History Departments of the British Museum and Keeper of Zoology at South Kensington. In 1907 he retired at the age of sixty.

Lankester's scientific inclinations appear to have been influenced by his early surroundings. In his own home he met such men as Darwin and Huxley and heard them discuss the biological problems of the day. He began his published writing as a mere boy. His first paper was on the fossil Pteraspis and appeared in *The Geologist* in 1862. This led later to the important monograph on "The Cephalaspidae" published in 1868–70.

In 1863 the Quarterly Journal of Microscopical Science published his first paper on the Gregarinidae. This was followed by numerous publications in the field of protozoology and parasitology. An early study (1864) of the anatomy of the earthworm led him to conclude that the earthworm is "the rock on which morphology is built." Comparative studies of invertebrates convinced him that annelids like vertebrates are coelomate, while the molluscs and arthropods have a different sort of body cavity which is filled with blood. In this way much light was thrown upon the racial history of animals. He demonstrated in his memoirs on Limulus that this animal is more closely related to the scorpions than to the crustacea.

His researches included the embryology of molluscs and of amphioxus. Many of the zoological articles in the Encyclopedia Britannica are his. He edited the well-known Treatise on Zoology. His popular writings are numerous. Among them are his books on "Comparative Longevity," "Degeneration," "The Advancement of Science," "The Kingdom of Man," "Science from an Easy Chair," "Great Things and Small." From 1878 to 1920 he was the editor of the Quarterly Journal of Microscopical Science, which under his direction became the leading British Journal in zoology.

He attained high reputation as a teacher. He was a man of commanding personal appearance, and his lectures aroused great interest through his infectious enthusiasm. His was the dominant influence which led to the establishment of the great Plymouth Laboratory.

Lankester was a Fellow of the Royal Society and of the Linnean Society. He was knighted when he retired from the British Museum. No man of his generation did more for the advancement of zoology as a science.

HERBERT V. NEAL.

HENDRIK ANTOON LORENTZ (1853–1928)

Foreign Honorary Member in Class I, Section 2, 1912

Hendrik Antoon Lorentz, born at Arnheim, Holland, July 18, 1853, died February 4, 1928, was a very great physicist and unique among the physicists of our times by the very true and deep affection in which he was held by all who knew him.

Lorentz was graduated from the University of Leiden in 1875, where he became Professor of Mathematical Physics at the age of 25, a position which he held until within about ten years of his death, when he accepted the position of directing the research at the Teyler Institute at Haarlem, retaining however the position of Honorary Professor at Leiden, where he continued to lecture once each week. Lorentz received "all the distinctions to which a man of science is eligible"; he was a member of nearly all the learned societies of Europe and many of this country. He was made Nobel Laureate in 1902.

His doctor's dissertation was concerned with the reflection and refraction of light by the methods of the then new Maxwell theory, and in fact this treatise played an important part in introducing the concepts of Maxwell to continental physicists. In this treatise he extended Maxwell's ideas from static fields to the rapidly alternating fields of optical phenomena. The influence of Maxwell's theory remained strong throughout his life and gave a vivid directness to his physical imagery which was always striking. Perhaps the most characteristic of his contributions was his development of electron theory. The initial steps in this long development were taken soon after his doctor's dissertation, and involved an extension of the Maxwell equations to those regions forever inaccessible to experiment inside the electron, and also involved a deduction of the properties of large scale matter by a suitable process of averaging over all the small scale fluctuations of the field in the neighborhood of each electron. Courage and insight were needed for a program involving such arduous labors of detailed elaboration at a time when the Maxwell equations had not been unequivocally established even for large scale matter, and when the existence of the electron was not much more than a brilliant intuition to explain the fixed proportions of electrolysis. The reality of the electron substructure of the physical world rapidly became a matter of physical conviction through the many successes of Lorentz's analysis; the most spectacular success in this field was his explanation of the splitting of spectrum lines in a magnetic field discovered by Zeeman. His development of electron theory perhaps reached its culmination in 1905 with the publication of his Columbia lectures under the title The Theory of Electrons, a work which for many years remained the standard treatise on this subject.

Hardly less important than electron theory were the results obtained by Lorentz from an extension of Maxwell's theory in another direction, to electromagnetic phenomena in moving bodies, a subject which Maxwell himself had not correctly treated. Lorentz succeeded in showing the necessity for the absence of all first order effects arising from the motion of an optical or electromagnetic system through an ether. The question of second and higher order terms, as in the Michelson-Morley experiment, proved more difficult, but Lorentz had by 1904 shown that the equations for any phenomenon in a uniformly moving system, when expressed in terms of certain transformed variables, are the same to terms of all orders as the equations in a stationary system expressed in terms of the quantities of ordinary measurement. It remained for Einstein to take the final step and give a different turn to the whole situation by postulating that the transformed quantities are the measured quantities in the moving system. Thus although Lorentz missed the final formulation of the theory of relativity, he came very close to it, and his transformation equations remain the basis of the whole theory and will always bear his name.

Electron theory and the theory of moving bodies are perhaps the two greatest creative results of Lorentz's genius. The later years of his life were spent partly in coordinating and expanding his own earlier results, and in various expansions of the newer physical theories. He retained in a highly unusual degree the power of quickly and sympathetically assimilating the new theories, which were often completely at variance with the concepts of his youth. I remember a lecture which he gave in Cambridge on the then new correspondence principle of Bohr which impressed me greatly by the freshness of his grasp and the illuminating power of his point of view. But the last years of his life will be more remembered for his lectures, which he delivered in every civilized country of the world, and for his masterly presiding at scientific meetings. With regard to this phase of his work

I cannot do better than quote from the understanding appreciation written by W. H. Bragg in Nature at the time of his death:

"For many years Lorentz naturally and by general consent took the leading place in every European conference of physicists. He had won the affection and respect of men of all countries. He could use several languages fluently and accurately. He could grasp quickly the meaning of a speaker and immediately on the termination of an address he could repeat its arguments and conclusions in such other languages as might be desirable, so that all present were kept in touch with one another. He never allowed a discussion to stray.

Nevertheless, even his great abilities and his sound judgment would not alone have made Lorentz the perfect president that he was. His success was due also to a wonderful and most attractive courtliness, to a humour that could express itself in not one language alone, and not least to the charm of a kindly and affectionate disposition. He was really beloved by all who sat under him. In his own field, and that no insignificant one, he was one of the forces that drew together men of different nations and brought them to a mutual understanding."

P. W. Bridgman.

DAVID GORDON LYON (1852–1935)

Fellow in Class IV, Section 3, 1887

David Gordon Lyon, the son of Dr. Isaac Lyon and Sarah Caroline Arnold Lyon, was born in Benton, Alabama, on the 24th of May 1852, and died in Boston, after a brief illness, on the 4th of December 1935. In 1884 he married Tosca Woehler of Leipzig, who passed away in 1904. Six years later he married Mabel E. Harris, who died in 1931; their son, David Gordon Jr., survives him.

Lyon was graduated A.B. from Howard College (Alabama) in 1875 and then entered the Southern Baptist Theological Seminary, where his instructor in Hebrew was Crawford H. Toy. He continued his studies in Hebrew and began his work in Assyrian at the University of Leipzig, where he received his Ph.D. degree in 1882. His doctoral thesis, published in 1883 under the title *Keilschrifttexte Sargons* as Volume 5 of the *Assyriologische Bibliothek*, contains the cuneiform text, a translation, and a commentary on the inscriptions of Sargon, King of Assyria.

At the suggestion of Professor Toy, who had been appointed Hancock Professor of Hebrew and Other Oriental Languages and had founded the Department of Semitic Languages at Harvard in 1880, Lyon was appointed Hollis Professor of Divinity in 1882, and began to teach courses in Hebrew, Assyrian, and other Semitic languages. Upon the retirement of Professor Toy in 1910, Lyon was transferred to the Hancock Professorship, and served as the chairman of the Division of Semitic Languages and History until he retired in 1922.

As early as 1887 Lyon had obtained some funds for the purchase of Babylonian tablets. Three years later, with a sum provided by Jacob H. Schiff, he purchased in various parts of Europe the first collections for the new Harvard Semitic Museum, of which he was appointed Curator in January 1891, and of which he remained in charge for forty years. From Mr. Schiff, Lyon also obtained funds for the erection of the Semitic Museum building, formally opened in February 1903, and substantial contributions for its maintenance.

During 1906–07 Lyon was in Palestine as Director of the American School for Oriental Research in Jerusalem. He returned there in 1908 when he directed, with Dr. Gottlieb Schumacher, the Harvard excavations at Samaria, continued during the two following years under the direction of Dr. George A. Reisner. In coöperation with the Fogg Art Museum, Professor Lyon organized in 1927 the Harvard-Baghdad School Expedition to Nuzi, near Kirkuk (Iraq), that carried on archaeological excavations during four seasons.

A scholar of exacting standards and uncompromising thoroughness, Professor Lyon wrote sparingly but well. His work includes, besides the inscriptions of Sargon (1883), an Assyrian Manual (1886; 2d edition 1892), studies on the Hammurabi Code (1904 and 1912), reports on the Harvard excavations at Samaria and at Nuzi and, with Drs. George A. Reisner and Clarence S. Fisher, two important volumes on the Harvard Excavations at Samaria (1924). With Professor George F. Moore he edited the *Studies in the History of Religions* presented to Professor Toy in 1912, and for twenty-two years (1912–1934) he was one of the editors of the Harvard Semitic Series.

Professor Lyon was a Fellow of the American Academy of Arts and Sciences, and a member of the American Oriental Society, of the Society of Biblical Literature, and of the Archaeological Institute of America.

A true Southern gentleman in aspect and character, dignified in bearing, kindly in spirit, deeply religious, Professor Lyon commanded the respect of his acquaintances and the affection of his intimates.

ROBERT H. PFEIFFER.[1]

ARTHUR ANTHONY MACDONELL (1854–1930)

Foreign Honorary Member in Class III, Section 2, 1919

Arthur Anthony Macdonell died December 28, 1930, four years after his retirement from the Boden Professorship of Sanskrit in the University of Oxford, which he had held from 1899.

His parents both came from the north of Scotland. His father went to India in 1841 as an Ensign in the 40th Bengal Native Infantry, rose to the rank of Colonel, and died at Mussoorie in 1870. Macdonell was born May 14, 1854, at Muzaffarpur in Tirhut (North Bihar). During the Indian Mutiny he was saved from death by the fidelity of an Indian servant. For some unknown reason he was sent for education to Germany, at first to a school at Dresden and then to the Göttingen Gymnasium (1870–75).

He began the study of Sanskrit and Comparative Philology under Theodor Benfey at the University of Göttingen; then entered Corpus Christi College at Oxford in 1876, where he continued his Sanskrit studies under Monier Williams. After taking his degree he pursued his study of Vedic literature under Max Müller and then took the Degree of Ph.D. at Leipzig with a thesis relating to the *Sarvānukramanī* of the Rig Veda, and with Comparative Philology and German as accessory subjects.

He was Lecturer in German (1880), Lecturer in Sanskrit (1884), Deputy Professor of Sanskrit (1888), and Boden Professor of Sanskrit at Oxford after the death of Monier Williams in 1899. Much of his time was devoted to the development of the Indian Institute, of which he was Keeper, and to the collection of books, periodicals, and manuscripts.

He devoted himself chiefly to the study of the Veda, the earliest literature of India, and dealt with this from the point of view of Comparative Philology and the early history of religions, although he was not a specialist in linguistics nor a profound student of religion and philosophy as such.

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[1] Abridged from a minute prepared with the coöperation of G. H. Chase and W. Thomson.

He was not a theorist, was not interested in broad and superficial generalizations, and did not propose new and ingenious speculations. Trained in critical and historical methods, his shrewd common sense, "industry and love of a definite outcome led to the production of substantial and accurate treatises," for "he was never captivated by the glitter of new and startling theories."

His *Vedic Mythology* (1897) is the most useful summary of that subject; his *Vedic Grammar* (1910) is the most comprehensive. The two volumes of his *Vedic Index of Names and Subjects* (1912), written with the help of A. B. Keith as collaborator, is the most generally known and the most useful of his works. His *Vedic Reader for Students* (1917), accompanied by the *Vedic Grammar for Students* (1916), gives an excellent selection of hymns from the Rig Veda for beginners. His *History of Sanskrit Literature* (1900) is the best known of his smaller works. *India's Past* (1927) is an excellent compendium of the literatures, languages, religions and antiquities of India.

Camping Voyages on German Rivers (1890) and *Camping Out* (1892) bear witness to his robust physical vigour and ardent love for the out-of-doors.

He made two voyages to India; the first in 1907, as the result of which he acquired a Library of about 7,000 manuscripts, the second in 1922–23, undertaken in order to deliver a course of lectures on Comparative Religion at the University of Calcutta.

WALTER E. CLARK.

ALFRED PERCIVAL MAUDSLAY (1850–1931)

Foreign Honorary Member in Class III, Section 2, 1914

Alfred Percival Maudslay was born on March 18, 1850 at Tunbridge Wells, England, the son of Henry Maudslay of Woolwich, a famous engineer and inventor, "one of England's finest craftsmen." He died on January 22, 1931 at his beautiful estate, Morney Cross, Fownhope, near Hereford, on a slope above the Wye commanding a view of Hereford Cathedral and in the distance the Black Mountains of Wales.

His education began at Harrow in 1863 and continued at Trinity Hall, Cambridge, from which he was graduated in 1872, when he gained a second class in the Natural Sciences Tripos. At school he tells us he was called "a barren tree" and "an arid desert." The untruth of these statements was soon shown.

Immediately after graduation, with a "great desire to see a tropical forest," he set sail with his brother for the West Indies. He visited Panama and traveled through a part of Guatemala.

His early life was filled with administrative positions in the English colonies, first at Trinidad and later in Queensland, Fiji, Tonga, and Samoa. His success as a colonial administrator was great. His kindly and sympathetic nature made him an ideal type to treat with the natives, and his name came near ranking very high in the history of the Pacific when he completed negotiations with the Samoan chiefs for the unreserved cession of Samoa to Great Britain. Unfortunately, a previous agreement between his country and Germany prevented any advantage being taken of his understanding with the Samoans.

His fame, however, which might well have rested on colonial administration, came from his archaeological investigations in Central America. His trip in 1881 was the first of seven undertaken from 1881 to 1894. He conducted these elaborate expeditions entirely at his own expense, together with photographing and casting. He writes:

> "I was at a loss to know how best to make use of my notes and collections, when Mr. Godman kindly offered to relieve me of all the expense of printing and the reproduction of plates, and to publish my work as an addition to the 'Biologia Centrali-Americana,' if I would supply all necessary photographs, drawings and plans, and a written memoir."

From this happy arrangement we have the four monumental volumes of plates and four of text covering Maudslay's archaeological work. These volumes have never been equalled in the excellence of the plates, the accuracy of the plans, and the detailed studies of the architecture and the carefulness of the drawings of the hieroglyphic inscriptions, done under Maudslay's direction by Miss Annie Hunter.

It is needless here to enumerate the ruins he visited, several of which he made known to the scientific world for the first time. His plans, drawings, and photographs of Palenque, Quirigua, Chichen Itza, and many of the lesser sites have never been superseded. Coming down the Usumacinta River, he was the first archaeologist to reach the ruins of Menche (Yaxchilan), anticipating by a day or two the arrival of Charnay, who came up the river.

In 1891, through the initiative and aid of the late Charles P. Bowditch, another great patron and scholar of Maya research, the Peabody Museum of Harvard University had a ten year concession with Honduras to explore at Copan.

In 1893–94, owing to the death of Mr. Owens, one of the archaeologists, no one was sent to the site by the museum, and Mr. Maudslay kindly consented to serve as its representative. In previous visits he had already examined the site, giving letters to the stelae discovered by him. While there in 1893–94, he completed the moulds of the inscriptions omitted from his earlier series and moulded others found by the museum.

Early in his studies of the Maya ruins, Mr. Maudslay was impressed with the great importance of the hieroglyphic inscriptions. He took special pains to photograph and mould, wherever possible, the hieroglyphs. From these Miss Annie Hunter made the famous drawings of the inscriptions which have been a boon to all students of this subject. As early as 1886 he recognized the formula of the beginning of many of the inscriptions. Part 2 (vol. 1) of the *Biologia* appeared in 1890, and on plate 31 he has a famous drawing, placing side by side the first glyphs of several inscriptions. These he names the "Initial Series" for the first time, and notes the difference between the inscriptions with numbers and those without, noting that the number in the first glyph is almost invariably nine. It is indeed probable that it was Maudslay who suggested to Goodman the possibility of the face numerals which Goodman later worked out. Maudslay also recognized the rosette form for twenty, and the double number on the Uinal glyph of what, later, was called the Secondary Series.

The list of his honors is a long one. In addition to being Honorary Fellow of Trinity Hall, he received the Hon. Sc.D. from Cambridge, and the Hon. D.Sc. from Oxford in 1912, in which year he was the President of the Royal Anthropological Institute and the Chairman of the Organizing Committee and President of the International Congress of Americanists in London. He joined the Royal Geographical Society in 1884, and was Honorary Secretary for several years. He was also a member of the Council of the Hakluyt Society. An Honorary Professorship in the Museo Nacional at Mexico City was something of which he was always proud. He also held Honorary memberships in the Société des Américanistes of Paris, the American Antiquarian Society, the American Academy of Arts and Sciences, and the American Anthropological Association, and was a corresponding member of the Berliner Gesellschaft für Anthropologie. In 1926 he received the Rivers Memorial Medal of the Royal Anthropological Institute.

He bequeathed his valuable Mexican manuscripts, books, pamphlets, and a very extensive collection of ancient maps to the British Museum, and his Fijian collection to the Cambridge University Museum. The invaluable Gouverneur Morris papers which he inherited from his wife were left to the Library of Congress, Washington.

Mr. Maudslay's aim was perfection, and his published scientific works show that his ideal was accomplished. As a scholar, he refused to be satisfied with hazy generalizations, and sought the truth. His gentle nature, his retiring disposition, and his great modesty were outstanding characteristics. He was without guile. One can often wonder as to his reactions to the modern scientific expeditions with their aeroplanes and motors, their staff of secretaries, moving picture operators, and, most necessary of all, publicity agents. His own splendid accomplishments were unheralded in the press, and were generally unrecognized except by a few faithful friends and fellow archaeologists until toward the last twenty years of his life. Mr. Maudslay's work can never be equaled. During the last forty years, time and man have worked havoc with the Maya ruins. Priceless records have now disappeared, but many of them are permanently recorded in the monumental volumes of the *Biologia Centrali-Americana*. And Maudslay's schoolmates at Harrow called him "a barren tree"!

ALFRED M. TOZZER.

GEORG ELIAS MÜLLER (1850–1934)

Foreign Honorary Member in Class IV, Section 1, 1933

Georg Elias Müller died in Göttingen on December 23, 1934, at the age of eighty-four, after a long life of distinguished service to experimental psychology. He was born in Grimma, Saxony, on July 20, 1850. He attended the University at Göttingen, and there he received in 1873, on the recommendation of R. H. Lotze, the doctor's degree in philosophy. He was habilitated as *Dozent* at Göttingen in 1876. After a year at Czernowitz, he succeeded Lotze at Göttingen in 1881, and he held this chair for forty years until his retirement in 1921.

Müller was one of the pioneers in the new experimental psychology. Wundt, eighteen years his senior, may be said to have got the new science 'founded' at Leipzig, but the chief support for it came presently from Müller at Göttingen, Stumpf at Berlin, and a few others, like Ebbinghaus and the physiologist, Hering. The contribution of Müller to psychology was distinguished by its diversity and thoroughness. In two fields, psychophysics and the experimental study of memory, Müller became the leading investigator and he dominated scientific progress for a time in these subjects by the extent and originality of his researches. In a third field, the psychophysiology of vision, he ranked for many years next to Helmholtz and Hering.

Müller took over the problems of psychophysics from Fechner. In 1878 he criticized and revised Fechner's methods, laying a more solid foundation for the technique of sensory measurement as it is practised today. Before the close of the century he had contributed notably to an understanding of the psychological mechanisms underlying successive comparison, and in 1904 he published his second critique of the psychophysical methods. These two monographs of Müller's stand out, with Fechner's writings, as the classical literature in the field of general psychophysics, a field which has been extensively developed in modern psychology.

Although it was Ebbinghaus who in 1885 initiated the experimental technique for the measurement of memory and learning, it was Müller who, during the next quarter of a century, developed the procedures and laid the foundation for our systematic knowledge of to-day. It was Müller who showed that the strength of an association determines the speed of the memory reaction as well as the correctness of the response. It was Müller who first discovered and described retroactive inhibition, the weakening of memory by mental work undertaken after learning. And there are many other classical problems in this field that go back to Müller for their inception.

Müller's contributions to the psychophysiology of vision began in articles that were published in 1896 and ended only with papers that have reached publication after his death. In this field he is best known for his theoretical insight, especially for his synthesis of Hering's and von Kries' theories and for his realization that the facts of color mixture require a cerebral as well as a retinal explanation.

For four decades Müller remained one of the world's chief experimental psychologists. His work and his writing were at all times characterized by a care and critical insight which has scarcely been surpassed among contemporary psychologists. He saw concrete facts always in relation to the larger systematic and theoretical structure of the new science. His research belongs to the period when the entire range of scientific psychology could lie within the purview of a single scholar, and psychology is not likely soon again to have a scholar who combines precision with breadth so successfully as did Müller.

EDWIN G. BORING.

SAMUEL PARSONS MULLIKEN (1864–1934)

Fellow in Class I, Section 3, 1912

Professor Samuel Parsons Mulliken[1] was a distinguished chemist, a fine character, and a great personality. Internationally known for his work on organic qualitative analysis in which field he was easily preëminent, he was also an inspiration to students of organic chemistry at the Massachusetts Institute of Technology and a model for them of the painstaking scientist unwilling to make his judgement until the evidence was complete.

The earliest recollections which I have of Professor Mulliken date from the time when I was a second-year student, spending my afternoons in the laboratory of analytical chemistry. He used frequently to walk through the long room carrying small glass capsules which he was accustomed to leave on the steam plate until their contents had been evaporated to dryness, for he was at that time working, as I later learned, on the second volume of his treatise on "The Identification of Pure Organic Compounds." The glass capsules were of a sort which were new to me, their contents looked interesting; and it seemed that the tall and scholarly appearing man who carried them so carefully, so intent about his business, must be a chemist of great erudition and manipulative skill. The next year, when I took his course in organic chemistry, I found the impression completely verified. The lectures were illustrated with unsurpassed experiments. Samples of all of the substances under discussion were circulated through the class. I learned to distinguish the odor of benzaldehyde from that of nitrobenzene. And I recall a beaker containing an aqueous solution of nitrobenzene, accompanied by a second beaker containing strips of sterilized filter paper which we dipped into the solution and tasted—and learned that the taste was sweet. Professor Mulliken was ready at all times to take the trouble to be clear. He seemed pleased that the students were mastering the intricacies of the subject, and the students learned the better for the sake of pleasing him.

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[1] The present notice is rewritten from an article, "Samuel Parsons Mulliken," in the American Contemporaries Series, *Ind. Eng. Chem.*, *News Edition, 12*, 197–198 (1934). An obituary by Avery A. Ashdown, with a portrait, was printed in the January, 1935, number of *The Nucleus*, published by the Northeastern Section of the American Chemical Society.

Samuel Parsons Mulliken was born in Newburyport, Massachusetts, on December 19, 1864, a descendant of the earliest white settlers of the Plymouth and Massachusetts Bay Colonies. Among his ancestors were Mullikens who were watch and clock makers and captains of clipper ships. He was named after his great-great-uncle Samuel Holden Parsons, a major-general in Washington's army and a member of the board which court-martialed Major André. While teaching at Technology he continued to live in Newburyport, and traveled back and forth to Boston by train. Taking into account the fact that he made the same trip daily while a student and that he came to the laboratory each day during a large part of the summer, a conservative calculation shows that he traveled more than a million miles on the Boston and Maine Railroad, more than four times the distance to the moon, or about six light-seconds. He did not seem to weary of the railroad, for one day in January, 1934, during the mid-year period, when traffic in Boston and Cambridge was paralyzed by heavy snow, he took a "snow train" for New Hampshire and went to Mt. Washington for a day of skiing.

His interest in chemistry, like that of Michael Faraday and many another, was first aroused by Mrs. Marcet's "Conversations on Chemistry." He once told me that he used to read the book while a small boy, lying on the dining-room floor. Two future chemists attended the Newburyport High School together, Mulliken from the south end of town and Arthur A. Noyes from the north end. At school they studied Steele's "Fourteen Weeks in Chemistry," and they studied the book outside of school. They secured a copy of Eliot and Storer's "Manual of Inorganic Chemistry," and experimented in their home laboratories, Wednesday afternoons in Noyes' laboratory in the attic of his father's house and Saturday afternoons in Mulliken's on the second floor of the woodshed. They used blotting paper for filtering, for the books called for "bibulous paper" and insurance advertising blotters were available without cost. One day, for some reason, they experimented in the dining room of the Noyes' home, where the large table provided a convenient workbench. A dictionary was used to support a portion of the apparatus. The experiment was the production of phosphoretted hydrogen by the action of caustic alkali on yellow phosphorus. The flask broke, and the effects upon the book, the table, and the rug were such that the boys thereafter experimented in the dining room no more. They did not confine themselves to chemistry, for they secured a copy of Hill's "Rhetoric" and studied it. Perhaps they had need of rhetoric to persuade their parents to allow them to continue their experimentation.

After he had completed his high-school course, Mulliken worked for two years in an apothecary shop at Newburyport, where he compounded prescriptions and found time to read Faraday's "Chemical Manipulation" and to carry on many of the processes which are described in that book. When he entered the Massachusetts Institute of Technology in the autumn of 1883, he was excused from the requirements in freshman chemistry. He received the bachelor of science degree in chemistry in 1887, after having performed the experimentation for his thesis under the direction of Lewis M. Norton. Under this man's cousin, Thomas H. Norton, he spent the academic year 1887–88 at the University of Cincinnati, where he gave experimental lectures and taught chemistry of all kinds.

In the summer of 1888 four Technology graduates went to Europe together in pursuit of advanced study. There were three chemists, Mulliken, Noyes, and Augustus H. Gill, and a student of music on his way to Munich, Frederic Field Bullard, author of the "Stein Song." When the boat reached Antwerp, the chemists found awaiting them a letter from Baeyer which informed them that all available places in the laboratory at Munich were already occupied. They decided to "shop around" among the German universities. They visited Heidelberg which seemed dead, and Bonn where they met Anschutz who showed them the beer gardens and introduced them to Kekulé who expressed an admiration for Americans—and they selected Leipzig as the place to continue their study. Here they were joined by Henry

P. Talbot, another Technology chemist. Mulliken worked with Wislicenus on the isomerism of the α- and β-chlorocinnamic acids. The relations between configuration and acid strength did not prove to be as predicted, and quantitative data were secured by measurements of the ionization constants in Ostwald's new laboratory of physical chemistry. While at Leipzig, Mulliken also took advantage of the opportunity to listen to Wundt's lectures on psychology and on the history of philosophy. The four Americans received their Ph.D. degrees from Leipzig in 1890, and a few years later were together again as members of the chemistry department of the Massachusetts Institute of Technology.

Mulliken spent the academic year 1890–91 as fellow in chemistry at the newly founded Clark University, and carried out researches on the electrolysis of malonic, acetoacetic, and orthoformic esters. He was associate in chemistry at Bryn Mawr for one year, 1891–92, and returned to Clark as instructor and acting head of the chemistry department for two years, 1892–94, until that department was discontinued for a time. During the next year he worked for a while in the private laboratory of Wolcott Gibbs at Newport, Rhode Island. From 1895 until the time of his death he was a member of the chemistry department of the Massachusetts Institute of Technology, teaching organic chemistry, a full professor after 1926. During the war he served as Major in the Chemical Warfare Service, U. S. Army, where his duties required him to act as immediate assistant to the chief of that service in many scientific matters.

Mulliken's principal interest was in the identification of pure organic substances, in their physical and chemical peculiarities, and he accumulated a vast fund of information on many special branches of organic chemistry. In addition to teaching general organic chemistry, he directed a number of Doctor's researches and gave courses on dye-stuffs, on heterocyclic compounds, and on organic qualitative analysis. The latter course gave a fine chance for graduate students to learn the manipulation of small quantities of material. The "Laboratory Experiments on the Class Reactions and Identification of Organic Substances," by Noyes and Mulliken, which was first published in 1897, was used for many years in connection with the third year organic laboratory course. Students were required to identify several unknowns and the components of two or three mixtures.

Mulliken's large work, "A Method for the Identification of Pure Organic Compounds by a Systematic Analytical Procedure Based on Physical Properties and Chemical Reactions," in four volumes, is a product of enormous industry and care. He spent more than eight years in the preparation of the first volume. The first three volumes list more than 10,000 compounds in their tables; the fourth volume deals with dyestuffs. The preface of the first volume says—"Very few compounds that could be purchased in the open market have been omitted except through oversight. . . . The claims for admission to this volume of every compound of carbon with hydrogen, or with hydrogen and oxygen, that receives mention in the second edition of Beilstein's great 'Handbuch der Organischen Chemie' and its supplements issued prior to January, 1902, have been separately passed upon, and about 2300 selected as deserving mention in the tables. All copied data used in the manuscript sent to the publisher have been twice compared with their source by the author and once by Dr. Heyward Scudder." More important even than the comparison with the literature is the author's assurance that many hundreds of the tests have been tried in his own laboratory. They were "performed at least several times in accordance with the directions contained in the manuscript" and had proved successful in the hands of two or more persons.

During most of his life Professor Mulliken spent the large part of the summers in his laboratory. Such recreation as he had he took out of doors. Toward the latter part of his life he occasionally spent as much as two months out of the summer at a cottage at Pemaquid, or more commonly took one or more two-weeks cruises along the beautiful rocky coast of Maine. Starting from Pemaquid in a 30-foot motor boat, usually in the company of one or more of the younger members of the organic chemistry staff of the Massachusetts Institute of Technology, he would cruise as far west as Portland and as far east as Mt. Desert and Bangor. He would sleep on board and would show as much facility in meeting the exigencies of the knockabout life of the small boat as he did in the manipulation of the most perverse of organic substances. In the spring of 1932 at the end of the school year, he organized among the organic chemists an all-day fishing trip to Ipswich Bay. It was so successful that the next spring a second boat was hired and the physical and inorganic chemists went along.

Professor Mulliken was a quiet man, reserved, almost shy. He spoke only after reflection and always took the kinder and more generous of alternative points of view. He was intensely devoted to his family, though he talked but little about his personal affairs and nonprofessional interests. He enjoyed his membership in the Tuesday Evening Club of Newburyport.

Professor Mulliken would have been seventy years old in December, 1934, and was planning to retire from active teaching in the spring of 1935. In the early summer of 1934 he was seized with an attack of rheumatic fever which compelled him to rest quietly for several months in the hospital at Newburyport, where he nevertheless indulged in correspondence and found pleasure in conversation with the friends who visited him. Convalescence appeared to be advancing satisfactorily; he was removed to his home but died there on the 24th of October.

TENNEY L. DAVIS.

CARL HANSEN OSTENFELD[1] (1873–1931)

Foreign Honorary Member in Class II, Section 2, 1928

Ostenfeld was born Aug. 3, 1873, at Randers in Jutland, where his father was established as a physician. He was educated at the University of Copenhagen, studying botany under Warming. He received his doctorate in 1906. Already, in 1900, he had been appointed to a post in the Botanical Museum at Copenhagen. This he held until 1918, when he became professor of systematic botany at the Agricultural College of Denmark. In 1923 he returned to the Museum as director. He died at Copenhagen, Jan. 16, 1931.

Such is the brief outline of a career devoted to the advancement of botanical science in Danish institutions, but by no means of a local cast. He travelled much in Europe. He made two voyages, in 1895 and in 1910, for the study of marine plankton, a subject in which he never lost interest and which he pursued at intervals nearly throughout his life. A paper on the plankton of Danish waters won him the Prix Desmazières in 1917.

During his first voyage he touched at some of the high northern islands; then began an interest in the plants of the Arctic which also was life-long. He projected a "Flora Arctica" and published one part of it, covering the pteridophytes and monocotyledons, in 1902. This effort convinced him that the data available were not yet ample enough for a really satisfactory flora; largely for that reason, he never published further, though his work on the subject never ceased and toward the end of his life he had begun to plan for a continuance of publication. At home, he organized a thorough-going study of the "topographic botany" of Denmark—the detailed distribution of all the species occurring there. With the cooperation of many Danish botanists, professional and amateur, work toward this end was carried on for twenty years. Publication of the results began in the year of Ostenfeld's death.

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[1] Taken from a notice by Carl Christensen in Berichte Deutsch. Bot. Gesellschaft, *49*, 1931, 164–168.

In genetics also, particularly as related to taxonomy, he showed both interest and ability. His early studies did much to establish the now well-known fact that the taxonomically complicated genera *Taraxacum* and *Hieracium* are, with the exception of a comparatively small group of species in the latter, capable of apogamic reproduction and generally dependent upon it.

Ostenfeld was a man of distinguished appearance and of kindly and attractive manner. He was a hard worker of the sort who never appear to hurry and yet whose product is surprisingly large. He lived to make himself the first authority on the flora of the North; that his comparatively early death prevented his putting his accumulated knowledge at the service of his successors is a misfortune often recurrent in a subject whose progress is likely to be too slow for the limits of human life.

C. A. WEATHERBY.

WILLIAM PATTEN (1861–1932)

Fellow in Class II, Section 3, 1921

William Patten was born at Watertown, Mass., March 15, 1861, and died at Hanover, N. H., Oct. 27, 1932.

A boy's interest in ornithology and anatomy, already acquired before he entered Lawrence Scientific School, ripened into a life purpose while he studied there under Professors Mark and Shaler. An essay on "Myology and Osteology of the Cat" written during his freshman year won him the Walker prize of the Boston Society of Natural History; and his skill as an illustrator and taxidermist helped his way through college. Though a hard worker he found time for baseball, college glee club and choir.

Awarded a Parker Traveling Fellowship when he graduated in 1883, Patten studied at the University of Leipzig under the zoologist Leuckart, and received his doctorate at the end of the year. Research followed: one year at Trieste and one at Naples. Returning to America in 1886, he was assistant for three years at the Allis Lake Laboratory at Milwaukee and then became Professor of Biology at the University of North Dakota.

In 1893 he was called to Dartmouth College by President William Jewett Tucker, where his vigorous personality and skill as an investigator at once stimulated interest in Zoology and laboratory methods. His writings at first dealt with the embryology of molluscs and arthropods, especially *Limulus;* but soon focussed more definitely on the nervous systems and phylogeny of ostracoderms, scorpions and primitive fishes. Out of these studies came Patten's theory of origin of the vertebrates.

With a paleontologist's enthusiasm he closed his workshop each summer to travel far afield in search of new material; and collected an amazing array of fossils from New Brunswick, Newfoundland, Labrador, Costa Rica, Cuba, New Guinea, Australia, Java, Japan, the Baltic region and Spitzbergen. Patiently and with fine technique he worked alone over these treasures, freeing fossils one by one from their muddy matrix and exposing to view delicate details of form and structure not previously known. More and more surely he came to believe that ostracoderms were the ancestors of fishes, linking invertebrates to vertebrates. This thesis, to which he devoted his energy and talents with even greater concentration while fellow scientists dissented with it, became the ruling passion of his scientific career. He spent little time in conference or argument with other experts in his field, preferring to get inspiration and guidance directly from Nature's record. While giving more of his time to solitary research than to attendance at meetings, Patten was a lecturer who invariably compelled attention through the force of his personality and the courage of his convictions, whether he was addressing a small group of obedient advanced students, a sympathetic popular audience or an assembly of skeptical colleagues. His presentation was always stimulating and provocative.

When in 1920, near the close of his service to the College, he was called upon to organize and direct a required course for freshmen in Evolution, he devoted his still abundant energy to the new task. So for a decade or more every student entering Dartmouth felt the impact of a man of science whose independent and skillful manipulation of the tools of laboratory and field bore fruit in a social philosophy whose keynote was "Co-operation."

Retiring from this over-strenuous service at the age of 70, Patten continued to collect and study Baltic fossils with undiminished eagerness; but his strength had failed and he succumbed to a heart attack after only a week's illness. He was survived for a year by his wife, Elizabeth Merrill Patten, who ever since his graduation in 1883 had been his constant companion, even on collecting expeditions to the corners of the earth. Their only son, Bradley Merrill Patten, born in Milwaukee in 1889, is now Professor of Histology and Embryology at the University of Michigan.

J. W. Goldthwait.

WILLIAM HENRY PERKIN, JR. (1860–1929)

Foreign Honorary Member in Class I, Section 3, 1919

William Henry Perkin, Jr. was one of the great organic chemists of the structural tradition. He was the son of the chemist who prepared the first coal-tar dyestuff, and grew up in an atmosphere of scientific research and technical development. He entered the Royal College of Chemistry in 1877 where he studied under Edward Frankland and W. R. E. Hodgkinson. In 1880 he went to Würtzburg where he studied chemistry with Wislicenus, physics with Kohlrausch, and mineralogy with Sandberger, and received the Ph.D. degree in 1882. In the autumn of 1882 he went to Munich to work with Baeyer—and became Privatdozent at the University, remaining until 1886. In 1887 Perkin became the first Professor of Chemistry at the newly founded Heriot-Watt College at Edinburgh. He left Edinburgh in 1892 and assumed the duties of Professor of Organic Chemistry at the Owens College, Manchester, succeeding Schorlemmer, where he remained for 21 years. From 1913 to the end of his life he was Professor of Chemistry in the University of Oxford, which he made one of the foremost centers of chemical research in England. His studies were devoted mainly to the development of the possibilities of synthesis and to the elucidation of the constitution of various organic substances which occur in nature.

An obituary notice, published as a special number of the *Journal of the Chemical Society*, London, 1932, contains a biography of Perkin by John Greenaway which describes his family life, his method of work, his love of music, etc., and is illustrated with three portraits and a picture of the Oxford commemorative medallion. It also contains an account of his work, in two sections, the first by Jocelyn F. Thorpe on his early work, the formation of carbon rings, the chemistry of camphor, the chemistry of the terpenes, and miscellaneous research, and the second by Robert Robinson on his work on the constitution of berberine, braziline and haematoxyline, harmine and harmaline, cryptopine and protopine, etc. A list of his original memoirs includes 271 titles of papers which were published during his lifetime and four more of papers which were posthumous.

TENNEY L. DAVIS.

ODIN ROBERTS (1867–1934)

Associate, 1928; Fellow in Class III, Section 1, 1932

Odin Roberts was born in Boston, January 22, 1867. He was educated in the public schools and at Chauncy-Hall School, and entered Harvard College at the age of fifteen. Graduating in 1886, he entered the Massachusetts Institute of Technology and received a degree there in 1888, and then studied law in the Harvard Law School, taking his bachelor's degree in 1891. All this was in preparation for the practice of patent law with his father, a distinguished patent lawyer. He practised patent law all his life with great success. He was also a very enthusiastic graduate of his University, one of the founders and president of the Harvard Club of Boston. He died July 23, 1934.

The chief quality of Roberts was his enthusiasm; and this quality filled with human interest a life that was devoted to a rather narrow profession. At a time when most men thought a Harvard club in Boston could never be successful he pushed it through by the very force of his enthusiastic friendships. His service to learning lies only in his devotedness to his profession for which he was prepared as well by a mechanical as by a legal education. His wide intelligence, however, gave him a deep interest in and appreciation of scholarship which was one of his most pleasant characteristics.

JOSEPH H. BEALE.

EDWIN ARLINGTON ROBINSON (1869–1935)

Fellow in Class IV, Section 4, 1927

The poet Edwin Arlington Robinson, son of Edward and Mary (Palmer) Robinson, was born at the village of Head Tide, Maine, on December 22, 1869. His childhood and youth were passed in the nearby city of Gardiner where after his first year his family lived in comfortable circumstances, and this was the only home he ever knew. He was educated in the schools of Gardiner and later spent the years 1891–1893 in Harvard College.

Critics of Robinson's work have seen in it, I think rightly, the clear mark of this early environment. He was and never ceased to be a Yankee, a Maine man, a Gardiner boy; and his friends know how much of Gardiner is in his Tilbury Town, how much of the common traits of his Gardiner neighbors in Isaac and Archibald, in Mr. Flood, in Richard Cory and in many of his other characters; how much of himself in Aunt Imogen.

The character of inflexible integrity, the principles and the preferences that were formed in Gardiner in the last third of the nineteenth century remained singularly unchanged throughout the first third of the twentieth. Thus, in much of his writing he was a regional poet whose life and work might well be analyzed by the method of Taine. Nevertheless, during the twentieth century he lived far from Gardiner, in New York, in Boston, and during many summers at Peterboro in the McDowell Colony where he found a way of living most happily suited to his needs, his habits and his taste.

While still a schoolboy Robinson turned to poetry. He has himself said,[1] "It was about my seventeenth year when I became violently excited over the structure and music of English blank verse" and this led to the singular experiment of a metrical translation of Cicero's first oration against Cataline. From his sixteenth year onward he wrote "innumerable short poems and sonnets." This early work was momentous in several respects. First, it was both absorbing and steadily, if on the whole involuntarily, persevering; as he says "There were such things as hours and days and weeks on clocks and calendars, but it made no difference to me how few or many of them went to my getting a few lines to go as I wanted them to go." Secondly, his early work was, as I have implied, consciously experimental—both metrically and verbally. He became "an incorrigible fisher of words." He wanted "the fish that were smooth and shining and subtle, and very much alive, and not too strange." And he also sought and found new tones. Thirdly, some of this was apprentice work done under the direction of a master. Robinson's master was a Gardiner physician, Dr. A. T. Schumann, of whom he has said "I am sure that he was one of the most remarkable metrical technicians that ever lived." To Schumann he felt and acknowledged a debt that he could not "even estimate." Though this debt was probably for technical instruction and professional formation alone, yet thereby Robinson's poetry was from the beginning distinguished from the poetry of the self-taught by firmness of touch and by consciousness of means no less than of ends. This is the fortunate result of an extraordinary chance.

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[1] This and the following quotations are from Robinson's article, "The first Seven Years," published in the *Colophon*, Part IV, 1930.

One outcome of his early work is described by Robinson as follows: "It must have been about the year 1889 when I realized finally, and not without a justifiable uncertainty as to how the thing was to be done, that I was doomed, or elected, or sentenced for life, to the writing of poetry. There was nothing else that interested me. . . . " Another result was the discovery of his own poetic idiom. He speaks of awareness of his early short poems and sonnets, "not being quite like anything else—or anything that I remembered."

Of a little later period he says, "I was still confident that the poems had nothing worse than a new idiom to condemn them," and then goes on to illustrate his idiom with the monosyllabic beginning of his sonnet "The Clerks,"—

"I did not think that I should find them there
When I came back again; . . . . . ."

This idiom, thus discovered and formed under such favorable conditions, is the unmistakable mark of his work throughout his life. Long unrecognized by the public, the critics and other poets, it seems to belong to the second decade of the present century, when it began to be widely recognized, felt and accepted, and thus became one of the most important factors in the development of recent American poetry. It is perhaps not often possible to discover so clearly a literary origin. That origin is in Gardiner about the year 1890.

Robinson's career from 1897 onward belongs to the history of American literature and this is not the place to discuss it. It is, of course, a period of growth accompanied by some development of his idiom, by the broadening of his scope, by the perfecting of his poetic skill. But meanwhile his single-hearted devotion to poetry, his conscientious craftsmanship, and his sense of professional responsibility never varied and he was always incapable of any other real work than the writing of poetry.

During the first two decades of his active life the new tones of the music of English verse that as a youth he had seized and made a part of himself were not heard or, though heard, were generally not recognized by the public. Thereafter almost suddenly they became familiar and are now at length a part of the common store of our auditory memory.

Robinson was the author of the following works:

The Torrent and the Night Before (1896)
The Children of the Night (1897, 1905)
Captain Craig (1902)
The Town Down the River (1910)
Van Zorn (play, 1914)
The Porcupine (play, 1915)
The Man Against the Sky (1916)
Merlin (1917)
Lancelot (1920)
The Three Taverns (1920)
Avon's Harvest (1921)
Collected Poems (1921)
Roman Bartholow (1923)
The Man Who Died Twice (1924)
Dionysius in Doubt (1925)
Tristram (1927)
Collected Poems (5 vols.) 1927
Sonnets (1928)

Cavender's House (1929)
The Glory of the Nightingales (1930)
Matthias at the Door (1931)
Nicodemus (1932)
Talifer (1933)
King Jasper (1935)

He received the honorary degree of Doctor of Letters from Yale in 1922 and from Bowdoin in 1925. He was thrice awarded the Pulitzer prize for poetry; in 1921 for the *Collected Poems*, in 1924 for *The Man Who Died Twice*, and in 1927 for *Tristram*. He was a member of the National Academy of Arts and Letters, of the National Institute of Arts and Letters, and in 1929 was awarded the Institute's gold medal.

Robinson died in New York City on April 6, 1935, having lived sixty-five years and three months.

L. J. HENDERSON.

GEORGE BYRON ROORBACH (1878–1934)

Fellow in Class III, Section 3, 1932

Professor George Byron Roorbach was born in Herkimer County, New York, on December 8, 1878. He died in Washington, D. C., on May 23, 1934.

He received his academic degree at Colgate College in 1903; in 1926 his alma mater conferred on him the honorary degree of Doctor of Science. His graduate study was carried on in Harvard University and the University of Pennsylvania, where he received the Master's Degree in 1912. His teaching experience was rich and varied. He held successively the post of high school principal (De Ruyter, New York, 1903–05); of science master (Peddie School, Hightstown, New Jersey, 1905–1908); of instructor and assistant professor of geography (University of Pennsylvania, 1909–19); of professor of foreign trade (Harvard Graduate School of Business Administration from 1919 until his death).

His interest and efforts in the subjects he taught, however, were not confined to the classroom. They naturally overflowed into the field of public service on the one side and writing on the other. He was fortunate in receiving and being able to respond to many calls which developed his contact with the realities involved in his academic work. In 1915 he made a special investigation of financial conditions in Venezuela for the Carnegie Endowment. In 1918-19 he was special expert for the United Shipping Board. It was during this service that he so favorably impressed former Dean Gay that he was offered the Professorship in Foreign Trade at Harvard. After coming to Harvard his work was repeatedly punctuated rather than interrupted by calls to government service. In 1921 he served the United States Tariff Commission. During the following year he was chief of the research division of the United States Department of Commerce. In 1926–27 he carried on an extensive special investigation of trade in the Far East for the Bureau of International Research of Harvard University. His death came at a moment when he was once more called upon by the nation to give it the benefit of his advice, this time in the capacity of special adviser on foreign trade for the Department of State. His numerous contributions to the periodical literature of foreign trade bear clearly the stamp of classroom discussion, though the metal out of which they were cast is just as clearly dug from business. His major works include *Import Purchasing,* 1927; *International Competition in Trade of India,* 1931; *Problems in Foreign Trade,* 1933.

Professor Roorbach was opposed to the isolationist or defeatist attitude on foreign trade that has been common since the world war. He believed that in the long run a liberal foreign trade policy would not only be justified under conditions of restored international society, but that it would materially hasten that consummation. He saw the difficulties and was particularly troubled by some of the current manifestations of fevered nationalism. But he never lost faith in the essential brotherhood of man. In fact, the only thing that seems ever to have roused the ire of this mild-mannered scholar was the sweeping condemnation of foreigners that according to him too often took the place of facts, reasoning and decent sentiment in discussions of the subject of which he was master, foreign trade. He was elected to fellowship in the American Academy of Arts and Sciences in 1932.

NATHAN ISAACS.

ERWIN FRINK SMITH (1854–1927)

Fellow in Class II, Section 2, 1914

When man hath looked deep into Nature's heart,
From dwarfing selfishness hath purged his own,
And upright, free and happy, shall be thrown
A god among the gods to play his part.
ERWIN F. SMITH, July 4, 1910.

Dr. Erwin F. Smith was born at Gilbert's Mills, N. Y., on January 21st, 1854. He died at his home in Washington, D. C., on April 6th, 1927. Short accounts of his life and work have appeared in *The Official Record,* U. S. Department of Agriculture, of April 20th, in *Science,* of October 28th, and in *Phytopathology,* of October, all in the year 1927. After graduation from the Ionia, Michigan, High School in 1880, he received his B.S. degree from Michigan University when he was thirty-two years old. He was thus late in graduating because he had to earn his way through these schools by teaching. In 1889 he received his Sc.D. degree from the latter institution.

During his teaching and student years in Michigan, he became acquainted with two men who had much to do with directing his future career in botany. These were Charles F. Wheeler and Volney M. Spalding. In their memory he makes this abbreviated statement in his text book on "Bacterial Diseases of Plants":—"The first showed me how to study flowering plants, open my eyes to the wonders of wood and field and was my companion in a thousand delightful rambles. From him I had also my first lessons in French. The second taught me how to study the parasitic fungus and where to find its literature, often reading it with me when it was in foreign tongues." He later was intimate with these men in the U. S. Department of Agriculture at Washington and elsewhere until their death.

In 1886 Smith went to Washington and there became associated with Galloway and his early assistants in developing the "Division of Vegetable Pathology," as it was then known. The writer first met him in 1893 when he was in charge of a Government exhibit at the World's Fair and last saw him when he was honored by the American Phytopathological Society at their annual dinner in Philadelphia on December 29th, 1926. These thirty-three years cover the time of Smith's most valuable and numerous publications.

As I write this article in the Library-Herbarium room here at the

Experiment Station at New Haven, I sit facing, on the wall, an enlarged photograph across the bottom of which is written in pencil *Erwin F. Smith.* This photograph, showing him in profile view, evidently was made at about the same time as that published in *Phytopathology* and is of a man past his prime in life but still vigorous and alert. His beard, cut in Van Dyke fashion, is quite white but his hair shows only an occasional grey thread. The lines at the corners of the eyes and the general aspect give the impression that here was a genial man as well as one of power. However, this picture bears little resemblance to the young, black-bearded man shown under the name of Smith (E. F.) in plate VIII of Smith's paper, "Fifty Years of Plant Pathology," published after his death in 1929, in the Proceedings of the International Congress of Plant Sciences at Ithaca. I like it even better than the picture, as a frontispiece to that article, which shows him in his laboratory coat and with a rather questioning look on his face.

There is no doubt that Dr. Smith was admired by his immediate associates at Washington as well as by his fellow botanists elsewhere. Not only was he a man who was very considerate to the many persons who came casually to his laboratory but he was decidedly helpful to those who stayed there for a longer time. The women scientists of the United States also owe him a debt of gratitude since he was one of the first to open his laboratory to them both as assistants and visitors. He recognized their ability as fine technicians in certain lines of botanical work. For this he has been repaid by their loyalty to him when hired as assistants.

Not only was this man a trained and well read botanist, who developed a fine personal library that he used in his leisure hours, but he became a great technician in his special line of bacteriology as well as an expert photographer. If Thaxter is to be ranked as our leading pen-and-ink mycological artist then Smith deserves to be considered as the leader for photographic pathology. Many of his articles contain half-tones of plant diseases while several of them use almost as much space as his written comments. Those who knew him best state that he was artistically inclined in other ways. He also had no small ability as a poet, having published a volume of his verses and certain translations. Altogether he was not only a fine botanist, great in his own line of plant bacteriology, but he was unusual in these other respects. It is, however, on what he discovered and what he wrote in a botanical way that his claim to fame must rest. He was honored by election to the presidency of various botanical societies as well as receiving other scientific preferments. Refusing chances for financial improvement elsewhere, he was content to remain with the laboratory he had established in the Department.

Dr. Smith began his botanical writings in 1881 and from 1886 until his death published, with few exceptions, one or more articles of this nature each year. Dr. R. H. True, in the *Phytopathology* article already mentioned, has given a very complete list of these papers, numbering two hundred and forty-three. Classifying all these writings rather vaguely, as is done here, we find that over one hundred deal with bacteria in some phase, about thirty with fungi, fourteen with virus troubles, twenty-four with flowering plants or their physiology, twenty-five with miscellaneous topics, thirty-five with reviews and translations and nine with biographies.

As with most of the older botanists, Dr. Smith's first publication was on the flowering plants. This was written with Charles F. Wheeler who was apparently the senior author. After Dr. Smith went to the U. S. Department of Agriculture in 1886, his writings for several years dealt with a variety of subjects, such as short articles on parasitic fungi and their control, reviewing articles on fungi by other authors, etc. Most of these were written for the Journal of Mycology, then published by the U. S. Department of Agriculture, under Galloway as Chief, with Smith as one of his assistants.

Soon, however, he became interested in a little understood disease known as Peach Yellows, a preliminary bulletin on which was published by the Department in 1888. It was his studies of Peach Yellows and related virus diseases, during the several years following, that would have made a name for Smith even if he had not become famous from his studies of bacterial diseases. His most important results with these virus diseases were the showing of their transmission by budding. His efforts with various fertilizers as cures, etc., were not so successful. He apparently came to believe that these troubles were caused by ultra-microscopic organisms. His work was too early to show, as did Kunkel later, that a species of leaf-hopper was the carrier of the disease. No one yet, however, has shown the real cause of such diseases.

While Smith in his early writings published some short articles and abstracts on fungi, he cannot be considered the leader in this line of work. Two of his largest and best publications are "Wilt Diseases of Cotton, Watermelon and Cowpea," and "Dry Rot of Potatoes due to *Fusarium oxysporum*," both U. S. bulletins.

It is as an investigator of bacteria, as the cause of plant diseases, that Erwin F. Smith made his reputation. While Burrill may be called the discoverer of bacteria as the cause of plant diseases, Smith should be known as the one who placed this phase of Bacteriology on a firm, safe basis. This is assured by his numerous articles on a great variety of bacterial diseases, too numerous to be mentioned here, as well as by his victory over Fischer in the noted discussion as to whether bacteria were the primary cause of certain diseases of plants. The final evidence is shown in his three-volume work, of nearly one thousand pages, entitled "Bacteria in Relation to Plant Diseases," as well as by his text-book, of nearly seven hundred pages, called "Bacterial Diseases of Plants," both copiously illustrated with drawings and photographs.

G. P. Clinton.

WILLIAM EDWARD STORY (1850–1930)

Fellow in Class I, Section 1, 1876

William E. Story was born in Boston on April 29, 1850, the son of Isaac and Elizabeth Story. He did distinguished and important work in several of the most recondite departments of pure mathematics, and was one of the pioneers in the establishment of high standards of mathematical research and mathematical education in the universities of this country. He graduated as A.B. at Harvard University in 1871, and was Parker Fellow there in 1874–75; from 1871 to 1875, he pursued mathematical studies at the Universities of Berlin and Leipzig, receiving the degree of Ph.D. at Leipzig in 1875; in 1875–76 he was Tutor in Mathematics at Harvard. Upon the opening of Johns Hopkins University in 1876, Story was appointed Associate (and shortly after Assistant Professor and Associate Professor) in Mathematics. In this capacity, he was the chief representative at Johns Hopkins of the methods and ideals of modern higher mathematics as cultivated in the universities of Continental Europe; for

Sylvester, though a great mathematical genius, and a most inspiring personality, was quite unfamiliar with the mighty advances that were being made by the mathematicians of Germany, France and Italy.

It was at Johns Hopkins that the first impulse was given to any systematic development of mathematical research in this country; and when Clark University was opened in 1889, its President, Stanley Hall, invited Story to be the head of its mathematical department, with a view to carrying out, in an even more intensive way, the purposes which animated the mathematical faculty at Johns Hopkins. How faithfully and enthusiastically Story devoted himself to this task may be seen from the Report on the first ten years of the Department of Mathematics in the Decennial Celebration volume issued by Clark University in 1899—a Report which, though written by Story, gives more generous space to the researches of the Assistant Professor, Henry Taber, than to his own. How extensive and varied, as well as profound, were Story's researches, may be seen from a glance at the titles of his numerous papers; the mention of a few of them must here suffice:

On the Theory of Rational Derivation on a Cubic Curve (Amer. Jour. of Math., 1880)
On the Non-Euclidean Geometry (Ibid., 1882)
A New Method in Analytic Geometry (Ibid., 1887)
On the Covariants of a System of Quantics (Mathematische Annalen, 1893)
New General Theory of Errors (Proc. Amer. Acad. of Arts and Sci., 1904)
Partial Pressures in Liquid Mixtures (Philos. Magazine, 1910).

Mention of the last-named paper is a reminder that Story, though chiefly interested in the problems of pure mathematics, was also interested in its application to physics. He also took a deep interest in the history of mathematics; and it may be added that he had a somewhat unusual penchant for puzzles which are interesting from a mathematical point of view.

As regards the training of students of the higher mathematics, and the bearing of that training upon the advancement of other sciences, Story states his views in the Clark Decennial volume, in a most vigorous and effective way; we see that, but for the want of means, what he would have built up at Clark University would have been just such an institution as is now being developed at the Institute for Advanced Study at Princeton, with Einstein as head of the department of mathematics.

Story was editor in charge of the American Journal of Mathematics from 1878 to 1882, editor of the Mathematical Review, and a member of the National Academy of Sciences. He was head of the Department of Mathematics at Clark University from its foundation until he retired as Emeritus Professor in 1921. He was happy in his marriage as in his work; his wife, whom he married in 1878, was Miss Mary D. Harrison of Baltimore. She and their only child, William E. Story, Jr., survive him. He died of pneumonia, after a very brief illness, April 10, 1930, having fulfilled, throughout a long life, the ideals of a devoted teacher and a single-minded lover of scientific truth and progress.

FABIAN FRANKLIN.

HENRY PAUL TALBOT (1864–1927)

Fellow in Class I, Section 3, 1899

Henry Paul Talbot was born in Boston, May 15, 1864, son of Zephaniah and Eliza Frances (Paul) Talbot. The family tradition has it that the Talbots were originally French, but came to England with William the Conqueror. At all events, they were among the earliest to settle in Massachusetts. Chief Justice Cushing, a friend of George Washington, and Commodore Silas Talbot are among the distinguished ancestors. Henry Talbot's father was in the United States Navy for many years, but resigned and became an industrialist, locating in Holliston, Massachusetts, where he owned a blanket mill and a tack factory. The mother was of Scottish parentage.

Henry Talbot grew up in Holliston and Boston. He graduated from the Holliston High School in 1881, and in September of that year he entered the Massachusetts Institute of Technology with which Institution he was identified throughout the remainder of his life. He graduated from the course in Chemistry with the degree of S.B. in 1885, and was immediately taken upon the staff where he served as assistant and instructor for three years. The following two years were devoted to study at Leipzig where he obtained the degree of Ph.D. *summa cum laude* in 1890. He majored in Organic Chemistry under Wislicenus, and he took courses under Ostwald in the then new field of Physical Chemistry. Returning to Technology he passed through the grades of Instructor 1890–1892, Assistant Professor 1892–1895, Associate Professor 1895–1898, Professor of Analytical Chemistry 1898–1902, Professor of Inorganic Chemistry and in charge of the Department of Chemistry and Chemical Engineering 1902–1920, in charge of the Department of Chemistry 1920–1922, Dean of Students 1923 until his death. In addition to the duties of the above mentioned offices he served as Chairman of the Faculty 1919–1921, and from 1920–1923 as Chairman of the Administrative Committee which conducted the affairs of the Institute following the death of Dr. Maclaurin until the appointment of Dr. Stratton.

Dr. Talbot received an honorary Sc.D. from Dartmouth in 1921. During the war he served as a member of the Advisory Board of the United States Bureau of Mines, Department of Gas Defense. In 1891 he married Frances E. Dukehart of Baltimore. They had a son in 1893 who lived only two years.

Dr. Talbot's great ideals were the advancement of education and of chemistry. He advanced those ideals through his work as an educator and administrator at the Institute of Technology, and by his services in many professional organizations, among which were the American Chemical Society, the Society for the Promotion of Engineering Education, the New England Association of Chemistry Teachers, the American Academy of Arts and Sciences. He was always an active leader in these organizations, in which he served, often repeatedly, in the capacities of President, Director and Chairman of Committees. He helped greatly to make of these societies active agencies for advancing the interests of Education and Chemistry.

It is not strange that, with his great devotion to these activities, his energy hardly sufficed for much personal activity in scientific research. His great contribution to productive scholarship was in enabling and encouraging his students and members of his staff to carry out researches. He appreciated fully the importance of research, but in his mind education preceded research, and he encouraged the members of the instructing staff of his department to do research work only to the extent that it would increase their capacity to teach. His work in life was to develop men to be chemists, teachers, industrial leaders, leaders in the development of pure science, and administrators. He himself did not attempt to do much to further the expansion of science, his function was to impart to others a love and understanding of science.

Dr. Talbot was thorough and conscientious to a fault, never sparing himself, and always following personally every detail in carrying on the work of his department. He always took a profound interest in the personalities of his students and members of his staff, and it was this personal interest as well as his great ability as a teacher which must be largely responsible for the careers of many of today's leaders in chemistry.

Dr. Talbot's great interest in the personalities of students quite naturally led him to the office of Dean of Students when he decided to retire from active teaching, and from 1923 to 1927 the students of Technology had a friend who would give them strong support through difficulties and discouragements, and encouragement when they were successfully progressing.

In Dr. Talbot's comparatively early death, June 18, 1927, the Massachusetts Institute of Technology, and the educational and scientific interests of New England, indeed of the whole country, lost a worker and a friend upon whom they had long relied for sound advice, helpful coöperation and leadership.

ARTHUR A. BLANCHARD.

EDWARD WYLLYS TAYLOR[1] (1866–1932)

Fellow in Class II, Section 4, 1924

Born in Montclair, N. J., May 7, 1866, the son of Alfred and Jane Brown Tucker Taylor, he attended public schools and entered Harvard College in 1884. During his four undergraduate years he made many friends, particularly a number of men who later practised medicine in Boston. He made philosophy his major subject, received honorable mention as a student, and wrote a dissertation for his commencement in 1888. He entered the Harvard Medical School the next year and obtained the Boylston Medical Society prize in February, 1891, with an essay entitled, "The Mental Element in the Treatment of Disease," published the same year.

After his graduation he went back to his home and then left for study in Europe spending the time from October, 1891, until September, 1893, in Germany, at Berlin and Freiburg. He became a student of Prof. Hermann Oppenheim in Berlin and showed so much promise that he was appointed assistant in Oppenheim's department, serving there one year. During this period he was largely concerned with the anatomy and pathology of the nervous system. There were at that time few laboratories devoted to neuropathology, either in this country or in Europe. It was, therefore, a rare opportunity to study under the leading clinical neurologist in Europe.

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[1] Condensed from *Archives of Neurology and Psychiatry*, Nov. 1932, Vol. 28, pp. 1182–1187.

In the autumn of 1893, he began the practice of neurology in Boston and soon became associated with the Harvard Medical School. As the result of his work with Oppenheim, he had become interested in the pathology of the nervous system, and his first connection with the school was in this department, under Prof. W. T. Councilman. On his first visit to Councilman, he showed him some very large and beautiful slides of the brain which he had cut and stained in Oppenheim's clinic. Such slides had never been seen here before and did much to recommend Taylor for the school position he sought. A small laboratory was, therefore, established as adjunct to general pathology with Taylor in charge of the very moderate amount of teaching which was considered sufficient for that day. The importance of neuropathology was recognized, however, by J. J. Putnam and W. N. Bullard and soon after a separate department was created.

In 1906, Taylor officially began his career as teacher of neurology as assistant to Professor Putnam, succeeding him in 1912, and continuing as the James Jackson Putnam professor of neurology until 1926, when with the regrets of all he resigned on his sixtieth birthday to become professor emeritus. It was as a teacher of clinical neurology that Taylor undoubtedly made his greatest reputation. With the individual student he was sympathetic and stimulating, with a small group he was lucid in his discussion, but before a large class his presentation was at its best. Such a clinic was seldom prepared in advance. He carried no notes. He often did not know about the patient to be presented, but by a few rapid, well-worded questions he obtained the essential symptoms and, with this as a start, he then developed with skill the clinical picture. His talk would be filled with reference to similar and contrasting conditions and illustrated with diagrams on the blackboard, always drawn by him during the lecture.

Although giving full credit to others, he disliked the pedantic method, and so omitted references, long words, dates, figures and complicated prepared diagrams in his effort to simplify his exposition. In this manner he brought neurology before the student as a vivid, intelligible subject, understandable even to the least interested of the class. It is not without reason that he was considered by many a student as the best clinical lecturer in the school. His clearness and simplicity also appealed to many graduate students in his successive years as "the chief" at the Massachusetts General Hospital.

Taylor established many connections with hospitals in cities near Boston. One of his particular interests was the Long Island Hospital, a city institution for chronic disease in Boston Harbor. Here he did his earliest pathologic work after returning from Berlin. Up to the time of his death, he served as secretary of the Board of Visiting Physicians. In his earlier days he did much of his teaching at this institution, and some of his best papers result from long clinical observation of chronic cases with correlated necropsy reports. His interests were also broadened by membership on the Massachusetts State Board of Insanity, and later as consultant at the Riggs Foundation in Stockbridge, in both of which capacities he served for a number of years.

From the time of his graduation from college he was always interested in the literary side of medicine. He served on the staff of the Boston Medical and Surgical Journal as assistant editor (1899–1912) and finally as editor (1912–1914, inclusive). Other activities included positions on the editorial board of the Archives of Neurology and Psychiatry, the Journal of Nervous and Mental Diseases, and the New England Quarterly. For many years he edited the Collected Reprints, department of neurology, Harvard Medical School.

His medical contributions consisted of nearly one hundred papers, many of them, before publication, being read before local or national societies. Particular interest was shown along two lines of thought: multiple sclerosis, which occupied his attention from the time of his earliest medical work in Oppenheim's clinic up to the latter years of his life, and psychotherapy, which was always prominent in his mind.

Outside of his medical work, Taylor had many interests. He wrote a number of papers on witchcraft, especially the medical aspect of the problem. In his later years he became a devotee of chess, and established an informal club in Boston which met frequently in his house. On the grounds of his summer home at Ipswich he built a small stone building, known as the "chess house," ingeniously devised in the shape of a chess "castle" where he could play a quiet game surrounded by pine trees which he himself had planted many years before. He particularly enjoyed the quiet friendship of medical colleagues and others, and for many years he was a member of a small medical dinner club. He was a popular member of his class in Harvard College, and often spoke at the reunion dinners. On Oct. 14, 1897, he married Elsie Brewster Howe, in New York. She and two daughters survive him. His death occurred on August 17, 1932.

Such in brief outline is the medical life of Taylor—a persistent worker, almost exclusively in his chosen field of neurology. Much good original work stands under his name, but without doubt his greatest contribution was of a personal kind. He was one of a rare group who know not the meaning of jealousy; on the contrary, generosity and honesty were his outstanding characteristics, endearing his associates to their chief in a manner not often attained. His was never the hand of the taskmaster. Though his love of his profession was great, his life was conspicuously balanced, for his participation in games and sports and his interest in even the trivial affairs of his friends were vital to him. Even-tempered, optimistic, alert, often humorous, these are some of the characteristics which come to mind when we think of Wyllys Taylor, not as a doctor, but as a friend.

James B. Ayer.
Henry R. Viets.

HENRY WEEDEN UNDERWOOD, JR.[1] (1895–1934)

Fellow in Class I, Section 3, 1933

Henry Weeden Underwood, Jr. was a Fellow of the Academy for less than a year, but during that time he was a regular attendant at its meetings and derived much pleasure from them. Quiet and unobtrusive in all that he did, he was more than usually shy and sensitive, quick to respond to friendship, with a huge capacity for work and for the enjoyment of his scientific interests. He was for many years a member of the American Chemical Society; later he joined the History of Science Society, and in recent years the French, German, and Dutch Chemical Societies. The journals which he received, his teaching which he planned with a meticulous attention to detail, his research, his writing, the daily newspapers of which he read regularly a considerable number, his devotion to the principles of the Episcopal church and his mystical satisfaction in its ceremonies, an occasional fishing trip with one colleague or a day in the woods with another, a constant readiness to find pleasure in the things which gave pleasure to his closest friends—these things made up his life. To those who had not yet penetrated his reserve or seen behind his diffidence, his quiet and regular comings and goings must have seemed to constitute a humdrum, dull, routine existence. But he was a man rich in inner resources. His classical education, superimposed upon his Yankee heritage, had given him a fine sense of values, a pleasurable appreciation of excellence—a profound satisfaction in a job well done whether his own or another's. He was beginning to enjoy life and to lead it productively.

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[1] An obituary notice by Avery A. Ashdown, with a portrait, was printed in the April, 1934, number of *The Nucleus*, published by the Northeastern Section of the American Chemical Society.

Professor Underwood was born in Wakefield, Rhode Island, on August 14, 1895. He attended the grammar school at Narragansett and graduated from the South Kingston High School in 1912. The whole of his formal higher education was acquired at Brown University where he was awarded the degrees of Bachelor of Philosophy in 1916, of Master of Science in 1917, and of Doctor of Philosophy in 1919. He carried out the research for the doctorate under the direction of Professor John E. Bucher, and remained at Brown University for one year longer as a Research Fellow. In 1920 he joined the Chemistry Department of the Massachusetts Institute of Technology as instructor of organic chemistry, a position which he occupied until his appointment as Assistant Professor in 1929. In 1930 he was commissioned Captain in the Specialist Reserve, United States Army, and from that time taught the chemistry of explosives to the group of Ordnance officers of the regular army which was sent each year to the Massachusetts Institute of Technology. He died on March 20, 1934. He had nursed his father who was ill with pneumonia, and was with him at the time of his death. He caught the disease himself and died three days later.

He was the author of two textbooks, "Problems in Organic Chemistry," McGraw-Hill Book Company, Inc., 1st edition, 1926, and "Experiments in Organic Chemistry," John Wiley & Sons, Inc., 3d edition by Moore and Underwood, 1927, both of which have been widely used in American colleges. The first of these proved of great value to graduate students who were studying for the doctor's examination, and is likely for some time to continue to be used for the same purpose. His researches, published for the most part in the Journal of the American Chemical Society, included studies on catalysis and on the effect of catalytic agents on the mechanism of reactions, studies on the decomposition of esters, studies in the diphenic acid series, and studies on the phthaleins tending to throw light upon the relations between color and chemical constitution.

Tenney L. Davis.

IGNATZ URBAN[1] (1848–1931)

Foreign Honorary Member in Class II, Section 2, 1914

So far, at least, as his biographers tell us, Ignatz Urban never went outside of Germany; yet he probably added more than any other one man to our understanding of the flora of the West Indies. The herbarium botanist is sometimes ridiculed; and, indeed, the ideal condition is found when the same investigator works competently in both field and study. But scarcely less is achieved when able collectors like Sintenis, von Türckheim, and Ekman can turn over their material to a closet taxonomist of Urban's learning, energy, skill, and judgement, with the resources of a great botanical institution at his command. Indeed, with him, this collaboration may well have achieved more than could have been accomplished in any other way.

Urban was born January 7, 1848, at Warburg. His father was a prosperous brewer. The son was educated at the Universities of Bonn and Berlin. At first he studied philology, but soon turned to botany. He was a pupil of Alexander Braunn, Karl Koch, Ascherson, and Kny. He served in the Franco-Prussian war, returning safely to take his doctorate in 1873 with a morphological and biological study of the genus *Medicago* as his thesis, and to assume a teaching position in a Berlin school. In 1878 he was appointed first assistant at the Berlin Botanic Garden, in 1883 curator, and in 1889 assistant director, a post which he held until his retirement in 1913.

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[1] Taken from a notice by Th. Loesener in *Berichte Deutsch. Bot. Gesellschaft.* xlviii, 1931, 205–225.

Urban's production, in a long and industrious life, was large and touched many lines of botanical investigation. In his earlier years he carried out and published upon several morphological studies—on certain features of the *Rutaceae* and *Loasaceae*, on *Bauhinia*, pollination in *Lobeliaceae*, etc. Later there were miscellaneous taxonomic papers outside the main current of his activities. He had a taste for history and skill in narrative; this talent was turned to good advantage in his history of the Berlin Garden and his accounts of the many botanical explorers of Brazil and the West Indies.

After Eichler's death, Urban took editorial charge of the monumental "Flora Brasiliensis," to which he had already contributed the treatment of several families. In the face of considerable difficulties, financial and scientific, he brought the work to a triumphant completion in 1906, sixty-six years after it had been begun by von Martius.

In the midst of all this, he never lost sight of his main interest, the flora of the West Indies—a subject to which, in conversation, he always returned sooner or later. A series of excellent collectors explored for him systematically the flora of the various islands; and as their sendings came in and were worked up, the results were published in the nine volumes of "Symbolae Antillanae"—Urban's chief work, already a classic, distinguished for careful and exact scholarship, critical insight, and the ability to organize a multitude of variant forms into practical and reasonable classificatory schemes which is the mark of the good taxonomist.

Urban continued to work with scarcely diminished vigor and keenness until four days before his death, on the morning of his eighty-third birth-day, January 7, 1931.

C. A. Weatherby.

CLAUDE HALSTEAD VAN TYNE (1869–1930)

Fellow in Class III, Section 3, 1924

Claude Halstead Van Tyne was born in Tecumseh, Michigan, on October 16, 1869. After an experience of several years in business, and having reached the position of cashier in a northern Michigan bank, he entered the University of Michigan, from which he received the degree of A.B. in 1896 at the age of 27. During his college years he undertook a 3,500-mile bicycle tour from Detroit across the Rocky Mountains (1894) and a similar trip of 2,500 miles in Europe (1895), meeting expenses by writing syndicated newspaper accounts of his adventures.

Upon graduation, he married Belle Joslyn of Chesaning, Michigan, and proceeded to Europe for study at Heidelberg, Leipzig, and Paris (1897–1898). They devoted a summer vacation to a 1,300-mile trip down the Danube in a rowing canoe, camping on the banks and writing the story of their expedition for a press syndicate. Returning to the United States, Van Tyne entered the Graduate School of the University of Pennsylvania as a candidate for the degree of Ph.D., which he received in 1900. His dissertation, *The Loyalists in the American Revolution* (1902) was a work of originality and great merit, and started him upon the field of research, the history of the American Revolution, to which he devoted his career. For two and a half years after receiving his degree, Van Tyne remained at Pennsylvania as teaching fellow in history, during which time he edited *The Letters of Daniel Webster* (1902), utilizing a mass of material which he had discovered more or less fortuitously.

In January, 1903, the newly-established Carnegie Institution of Washington made provision for historical research in the form of an exploration and inventory of the archives of the Federal Government, and Van Tyne was invited (with W. G. Leland) to undertake the investigation. The results of their joint labors were published by the Carnegie Institution in 1904: *Guide to the Archives of the Government of the United States in Washington*. During the six months that Van Tyne spent in Washington upon this task, he also made a substantial beginning of his one-volume history, *The American Revolution*, still one of the best short histories of the period, which was published (1905) in the coöperative history of *The American Nation*, edited by Albert Bushnell Hart.

When, in the autumn of 1903, Andrew C. McLaughlin, head of the Department of American History at the University of Michigan and Van Tyne's professor and early source of inspiration, went to Washington on leave of absence to organize the Department of Historical Research of the Carnegie Institution, Van Tyne was called to give his courses at Michigan, where he was appointed an assistant professor. In 1906 he was appointed professor and succeeded McLaughlin as head of the Department of American history, later (1911) becoming head of the consolidated Department of History. Thus it was at Michigan that most of his academic life was passed.

Although he devoted himself with singleness of purpose to the principal task that he had set for himself as a graduate student, the writing of a major and definitive history of the American Revolution, he had many and varied interests. Those of the University always commanded his devotion, and he built up there one of the strongest departments of history in the country, and was instrumental, through his friendship with William L. Clements, in securing for the University the incomparable research library in American history that bears its donor's name. He was active in regional historical activities, and was president of the Michigan Historical Commission. In the affairs of the American Historical Association he also took an influential part and, for seven years, was a member of the Board of Editors of the *American Historical Review.*

In 1913–1914 he spent a sabbatical year in Europe, chiefly engaged in research in archives and libraries, and lectured in the provincial French universities on the James Hazen Hyde Foundation of the Cercle français of Harvard University. In 1921 he went, upon invitation, to India to observe the operations of the Indian Act of 1919, and published *India in Ferment* (1923). In 1927 he held the Sir George Watson lectureship in the British Universities, his lectures being published as *England and America, Rivals in the American Revolution.*

Meanwhile, his magnum opus was progressing. The first volume, *The Causes of the War of Independence,* appeared in 1920; the second *The War of Independence: American Phase,* in 1929. As he was pushing the work on the third volume, there appeared the symptoms of the long illness that was to bring his career prematurely to a close, and he died on March 15, 1930, at the age of sixty-one. His death, with his great work half finished, may be truly said to be an irreparable loss to American scholarship. Posthumously he received the Pulitzer Prize.

Van Tyne was an outstanding American historian, and was freely conceded to be foremost in his own field. Exacting of himself, he judged his own work and that of others by the highest standards.

An unequalled mastery of his sources, enlightened by an original point of view, made it possible for him to make a fresh and important contribution in a field long worked by many scholars.

WALDO G. LELAND.

WILLIAM CUSHING WAIT (1860–1935)

Fellow in Class III, Section 1, 1914

William Cushing Wait, a Justice of the Supreme Judicial Court of Massachusetts, died in Medford, Massachusetts, January 28, 1935 after a year's illness due to overwork.

He was graduated from Harvard College in 1882, the tenth in his class, being awarded highest honors in history and an "oration." Three years later he was graduated from the Harvard Law School and at once entered upon the practice of his profession, at first in the office of Nathan Matthews, and later on his own account, until early in 1890 when he was invited to a partnership with Samuel J. Elder (Yale '73), then a leader in his profession. This association lasted until June, 1902, when he was appointed a Justice of the Superior Court of Massachusetts where he served until his promotion to the Supreme Judicial Court on December 19, 1923.

In 1907 he wrote for the report on the twenty-fifth anniversary of his graduation from college:

> "Since appointed Justice of the Superior Court June 4, 1902, I have attended to my duty and my history is blank beyond that. To be heard of publicly, a judge must be a very able one or a mighty poor one. I know I am not the first and I hope I am not the second."

Notwithstanding this show of modesty, he met the general approval of the bar by courtesy, fairness and the justice of his decisions. In the higher Court his contact with the bar was greatly lessened. His opinions, which averaged about fifty per year, are marked by lucidity and conciseness and show profound study and knowledge of the law he was called on to administer.

In the years before his appointment to the Court necessarily ended political activities he was an active member of the young Cleveland Democrats, serving steadily on the city and town committees of that party and, at three elections, was a defeated candidate for the State legislature, although he was told, he says, that "he could have anything he wanted if he were a Republican."

He took an active interest in civic affairs. He was a member of the Commission that drafted the charter for the City of Medford, was elected to the first board of Aldermen and drafted the city ordinances. He was active in support of "no license" under local option and in the successful enforcement of the liquor laws. For many years he served as a member of the Medford School Committee and of the Sinking Fund Commission. In church matters he was a trustee of the Ministerial Fund of the Unitarian Church and for thirty years its secretary. Such is his catalog of ships.

His interests were many. He was deeply interested in music and a devoted member of the Harvard Musical Association. As a member of the Appalachian Mountain Club, despite a shortening of one leg, he was a mountain climber. His election as president of the Alpha Chapter of the Phi Beta Kappa Society brought him deep satisfaction. He was an active fellow of the Academy, and his membership in other societies, both scientific and legal, indicated his interests. While he reported to his college class on the occasion of his fiftieth reunion that "Work has been heavy," he found time to serve on a Commission on the Law's Delays.

He fully merited President Eliot's highest praise for a noted lawyer—"He was a useful citizen."

EDMUND A. WHITMAN.

WINSLOW WARREN (1838–1930)

Fellow in Class III, Section 1, 1919

Winslow Warren—lawyer, man-of-affairs, public servant, historian, distinguished in all these fields—was born in Plymouth, Massachusetts, on March 20, 1838, the only son of Dr. Winslow and Margaret (Bartlett) Warren. His ancestry is set forth in an admirable memoir by William V. Kellen, in *Proc. Massachusetts Historical Society*, vol. 64, January 1931, which has been freely used in the preparation of this notice. This family history should interest the geneticist as well as the genealogist, representing as it does the purest Pilgrim descent on both sides of the house, with the Winslow, Bartlett and Warren strains—all able and all strongly characterized—predominant.

Winslow Warren was a delicate child but must have strengthened as he grew older, for he lived vigorously more than 92 years! He went through the Grammar School and High School at Plymouth and was preparing for Harvard (the college of both his grandfathers) when the straitened circumstances of the family nearly led to his abandoning his education for a business chance with an uncle in New York. In accordance with sound Plymouth tradition, however, the family sacrifice was made, and he became a member of the Harvard Class of 1858, in which he ranked high and had a Commencement part on "The Character of the Slave in the Roman Empire." After some indecision he determined to study law, which he did for a year in the office of his distinguished kinsman the brilliant Sidney Bartlett then the leader of the Suffolk Bar; then he went to the Harvard Law School, from which he graduated in 1861. In the same year he was admitted to the Suffolk Bar—on the strength of his record and without examination!—and immediately "hung out his shingle." His family connections seem to have brought him at once some practice which his native capacity and character enabled him to extend rapidly. Moreover in March, 1864, after having refused appointment as Clerk of the United States Circuit Court, he was appointed a United States Commissioner, which office he retained for no less than thirty years—to March, 1894—and which brought him to public notice.

This success made financially possible his marriage, on January 3, 1867, to Mary Lincoln Tinkham, daughter of Spencer Tinkham, a Boston merchant, by whom he had four children—Charles, Margaret, Mary L. (Hussey), and Winslow.

The story of his life from this point on is one of steady professional and business advancement. Besides scholarly instincts and a universal good-will, he had practical shrewdness and a character which inspired affection and confidence. It was the era of fast growing wealth and the rapid expansion of the system of trusts for the management of family fortunes. Inevitably he was drawn into this field of responsibility for other people's property. Through his uncle, Charles H. Warren, who was President of the Boston & Providence Railroad, he early became Clerk of that corporation and then Associate Counsel for the road and as such handled for many years much miscellaneous legal business, including the wise and just settlement out of court of the hundreds of cases, involving millions of dollars, growing out of the dreadful "Bussey Bridge disaster" in 1887—a truly remarkable feat.

His interest in things political was marked. Even before he was old enough to vote he had served as delegate from Plymouth to the last Whig convention, held at Worcester, and on attempting to register as a voter in Cambridge on the basis of his residence there while attending Law School, his youthful eruption in politics was resented in the Board of Aldermen which then controlled the voting lists. Mr. Warren won the suffrage only through the casting-vote of the Mayor! During the Civil War he became a "War Democrat," and a Democrat he remained all his life, though a frankly independent one. This, coupled with a certain originality in his opinions and positiveness and tenacity in those opinions when once formed, probably prevented his holding elective office although, in his only candidacy, he very nearly carried as a Democrat the rock-ribbed Republican town of Dedham! Forward movements in politics appealed to him. He was active in the early days of Civil Service Reform and in the founding, in 1885, of the Massachusetts Reform Club of which he was President from 1900 to 1902. He was a leader in the famous "Mugwump" campaign of 1884 and so came in close contact with Cleveland whose respect and friendship he won with the result that on February 27, 1897, in Cleveland's second term, he was appointed Collector of the Port of Boston. By tradition and in practice this post involves not only financially important and technically difficult administrative work, largely of a quasijudicial nature, but makes the incumbent the chief local political representative and mouth-piece of the administration in power. It is, therefore, a remarkable tribute to the public impression made by Winslow Warren's performance of his functions that, when McKinley succeeded Cleveland, he was kept in office until the expiration of his term, February 14, 1898, to the great satisfaction not only of commercial Boston but of all who value probity, scrupulous fairness, practical capacity, promptness and universal courtesy in high places.

In 1871, four years after their marriage, Mr. and Mrs. Warren, already prospering, removed to Dedham. There he identified himself with every good local work. Active in town-meetings, repeatedly Moderator, trustee of the Dedham Institution for Savings from 1872 to his death and President from 1904 to 1911, trustee of the Dedham Public Library, President of the Dedham Water Co., Chairman of the Committee on the Celebration of the Town's 250th Anniversary, it would be tedious to list all his contributions to Dedham's social, political, business and intellectual life. In Dedham he built a pleasant house overlooking the river valley and there, to the end of his long, busy and useful life, he passed his days. His native Plymouth still claimed a share in him, however, and there for very many years, he spent his summer vacations.

It remains to speak of certain other interests. His taste for history blossomed into considerable activity as evidenced by a substantial list of addresses and papers. Naturally enough his field was chiefly—but not wholly—early New England, and he became an important factor in most of the appropriate organizations. As early as 1870 he was a member of the Massachusetts Society of the Cincinnati, and served it in almost every possible capacity including the Presidency, while in 1902 he became President of the General Society and so remained till his death, presiding over nine of its Triennial Meetings with vigor and enjoyment, the last being in his 92d year. He was elected to the Massachusetts Historical Society in 1873 and inevitably served it in various posts (including six terms as Vice-President) besides contributing important gifts, papers, and addresses, as well as memorials of no less than twenty-one friends in the Society whom he outlived. From 1918 on he was the senior member. Other organization interests in this field were the Pilgrim Society, Society of Mayflower Descendants, Bunker Hill Monument Association (President 1897–1905), and the Colonial Society to which he contributed several excellent papers.

Still another set of interests centered around his vigorous religious beliefs as a Unitarian. He was President of the Massachusetts Congregational Charitable Society from 1911 to 1926 and of the Society for Propagating the Gospel among the Indians and others in North America from 1910 to 1919. For several years he was President of the Unitarian Club of Boston and was active in the American Unitarian Association, several times presiding at meetings.

Nor does this exhaust the list of his organization interests for he served as President of the Economic Club of Boston, and was an incorporator, and from 1905 to 1908 President, of the University Club of Boston. His own University could not fail to claim his much-sought counsel and he was elected an Overseer of Harvard College in 1898 and re-elected in 1904.

On March 14, 1924, after more than 57 years of happy married life, his wife died; and on April 3, 1930, he himself passed peacefully away in his 93d year, active and interested in life almost to the close. He was survived by all his four children except Winslow Warren junior, who died November 13, 1927.

The life above sketched was not sensational, perhaps; Winslow Warren himself called it only "fairly successful." Most would deem that much too modest. In any event that life had two marked characteristics. It was eminently satisfactory to those among whom it was lived and it was satisfactory to him who lived it. It was a happy life, and spread happiness. Winslow Warren fully solved the biological problem of adaptation to his environment. He knew how to live. He was "the Good Neighbor." Mr. Kellen has said that he "took Plymouth Rock for the corner stone of his character," and surely of the Pilgrim tradition which he loved he was not the least among the exemplifiers.

FRANCIS N. BALCH.

WILLIAM HENRY WELCH (1850–1934)

Fellow in Class II, Section 4, 1897

The death of Doctor Welch in Baltimore on April 30, 1934, at the age of eighty-four, closed a life of extraordinary fullness and significance, and marked the end of an era of magnificent pioneering in American medicine, of which Dr. Welch was the acknowledged prophet and leader.

Welch grew up in an environment saturated, as it were, with medical interests. His grandfather, father, and his father's four brothers were all doctors. His father, William Wickham Welch, distinguished beyond the rest, was notable among the practitioners of his period and highly regarded by the community of Norfolk, Connecticut. After his death a memorial fountain was erected in his honor; it stands beside the house in which he lived and in which his gifted son was born. The elder Dr. Welch's social interests extended into politics, through which he was carried into the legislature of the State of Connecticut and into the House of Representatives in Washington. Hence the son came naturally not only by his medical, but also his strong humanitarian instincts.

Graduating in 1870 from Yale College, William H. Welch entered the College of Physicians and Surgeons (now Columbia University) in New York, but almost immediately after left there in order to pursue for a year advanced studies in chemistry at New Haven. This unusual act, considering the highly important part which organic chemistry was to play in the science and art of medicine, was not an impulsive gesture: it marked a particular quality of mind which sought to attain the fundamentals of knowledge, for the same kind of discrimination was displayed in a wider and deeper way when Welch became a student in Germany.

In 1874, Welch entered on an eighteen months interneship at Bellevue Hospital in New York, the significant event of which was the opportunity to study pathology under the influence of Dr. Francis Delafield. The two succeeding years were spent in Germany under masters of anatomy, physiological chemistry, physiology, and pathology. Although the purpose had been to add to his knowledge of internal medicine, with neurology as a specialty, the resistless pressure of his mind was for fundamental knowledge. Hence Welch found himself at the end of that pregnant period a marked and accomplished pathologist with an exceptionally broad scientific training.

Pathology offered no independent career in the United States at that time. On his return to New York, Welch engaged in practice while, as professor of pathology, from 1878 to 1884, at the University and Bellevue Hospital Medical College he taught, investigated, and indeed gave the first real course in pathology ever offered in America.

Dr. Welch's European reputation and the success of his teaching in New York brought his definitive opportunity when in 1884 he was called to the Johns Hopkins University. The purpose was to guide the selection of the staff of the Johns Hopkins Hospital, then under construction, and of the associated medical school supposed soon to be created. But the immediate task was to perfect himself in bacteriology, just then becoming essential to the development of hygiene, and the more effective practice of medicine. Hence he returned to Germany for a year's study under Robert Koch and his pupils. On his return in 1885, he established a laboratory of pathology at Johns Hopkins University which was all embracing and included, besides gross and microscopic pathology, pathological physiology (experimental medicine) and bacteriology. No one before him, even in Europe, had attempted so ambitious an undertaking; and his success was a tribute to his learning, his gifts as a teacher and influence as a stimulating investigator.

Dr. Welch's professional career in Baltimore was a long and distinguished one, and can be divided into three parts: from 1884 to 1916 he was professor of pathology; from 1917 to 1926, Director of the School of Hygiene and Public Health; and from 1926 to 1931, professor of the history of medicine. In all three of these important branches of learning, Welch not only became the leader of thought and action, but he created the means whereby action could be secured.

We have seen that he organized the first comprehensive school of pathology. He created as well the first model school of hygiene and public health, which was to be imitated abroad a few years later; and between his 75th and 80th years he conceived and established the department of the history of medicine, associated with the library which bears his name, conducting the teaching and research until his retirement at the age of eighty-one. In fact, Welch never actually retired from his professorial offices, for until his last illness he retained his extraordinary mental and physical vigor so fully that his brilliant intellectual activities can be said to have ceased only with his life.

This brief review does not take account of Dr. Welch's exceptionally broad general culture which included literature, history, and the arts, nor does it exhaust the significant professional undertakings in which he became engaged. He may be viewed as having been educator at large in the modernization and expansion of higher medical teaching and research in America, and his influence was potent also in the field of general, as distinguished from medical, science. As a member of the board of trustees of enterprises such as The Rockefeller Institute for Medical Research in New York and the Carnegie Institution of Washington he took a leading part in guiding their essential policies. He served also on state and national boards of health, and thus aided in securing the improvements in public health administration still going on widely in this country. Welch was active also in connection with scientific societies at home and abroad, and filled high offices in these important organizations. He was for four years president of the National Academy of Sciences, and took a leading part in the establishment of the National Research Council. He virtually founded the *Journal of Experimental Medicine*, the first strictly scientific medical periodical in the United States, and was its editor for several years. Honors were conferred upon him by institutions of learning and governments at home and abroad. On his seventieth birthday his collected papers were assembled in three impressive volumes, while his eightieth birthday was celebrated with a large public function in Washington at which the President of the United States spoke, and concomitant celebrations were held in many other cities in the United States and even in Europe and Asia.

SIMON FLEXNER.

RICHARD WETTSTEIN[1] (1863–1931)

Foreign Honorary Member in Class II, Section 2, 1927

In Wettstein modern botany, particularly in its phylogenetic aspects, lost one of its chief exponents. He was born at Vienna, June 30, 1863, and died at Trins in the Tirol, August 10, 1931. While still an undergraduate, he became assistant in the Botanic Garden at Vienna under Kerner von Marilaun. In 1892 he was appointed Professor of Systematic Botany in the German University at Prague, whence he was called back to Vienna in 1899 to fill the position as head of the Botanic Garden left vacant by the death of his old chief, Kerner. His first published work was in physiology, but his bent was always toward floristics and taxonomy and in this Kerner had encouraged him. Already, at Prague, he had published monographs of several critical genera, the treatment of the *Scrophulariaceae* in Engler and Prantl's *Pflanzenfamilien,* and a work on the principles of plant classification; the rest of his work was in this direction. He was a skilful and inspiring teacher; when, in 1901–1908, he brought out his *Handbuch der systematischen Botanik,* he put into it the lucidity, the grasp and the stimulating quality of his justly famed lectures. Though it ranks as a text-book and has been widely used as such, it is no mere compilation. It is rather an original essay on classification; the arrangement of families, much of the detail, and the phylogenetic hypotheses are particularly Wettstein's own.

He was a hard worker, "a skilful organizer, persuasive in speech and manner and a shrewd manager of men and situations."

C. A. WEATHERBY.

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[1] Abstracted from a notice by Otto Stapf in *Proc. Linn. Soc.*, London, 1931–32, 194–196.

DAVID WHITE (1862–1935)

Fellow in Class II, Section 1, 1921

David White was one of the leading paleobotanists of the world. His knowledge of the fossil plants of the Paleozoic was probably unsurpassed.

He was born in Palmyra, New York, of early pre-Revolutionary stock, the youngest of a family of eight. Botany was a boyhood interest which came to assume a dominant place in his intellectual activities. At Cornell University, where he took the B.S. degree in 1886, he acquired a sound training in Geology and Paleontology, and became especially interested in the Devonian plant fragments found in the vicinity of Ithaca; these formed the basis for his bachelor thesis.

Upon graduation he joined the staff of the U. S. Geological Survey as assistant to the paleobotanist Lester F. Ward. He remained with the Survey until his death, becoming Senior Geologist in 1922. He was also Curator of Paleobotany in the Smithsonian Institution from 1903 to his death.

White's first paleobotanical publication was on the Cretaceous of Gay Head, Martha's Vineyard, in 1890. He had, however, already begun to study the floras of the Carboniferous, his first contribution on which appeared in 1893. His first large publication was *The Fossil Flora of the lower Coal Measures of Missouri.* This comprised Monograph 37 of the U. S. Geological Survey and is an authoritative work. Since Dr. Ward was primarily interested in the Mesozoic floras, David White soon began to specialize in the practically unoccupied field of the Paleozoic. He rapidly became the foremost Paleozoic paleobotanist of North America.

It was not alone the classification and description of fossil plants that interested White; he sought to interpret the facts he observed and recorded. The environmental conditions of these ancient floras aroused his keen interest, and in his later years he brought out much data as to the temperatures in which they had lived. For the understanding of the environment of the vegetation of past ages it was essential that he study the sediments in which it is preserved. Such study throws much light not only upon the physical conditions of the place of deposition and of the region where the sediment particles were broken from the parent rock, but of the nature of the area through which the streams flowed carrying this sediment to its place of deposition. White thus developed into a stratigrapher of high rank.

He embodied his extensive study of the fossil plants of the Grand Canyon of the Colorado in many papers, and wrote much on Paleozoic climate as indicated by fossil plants. The study of the flora of the Coal Measures led him into a consideration of the coal itself, and he became a foremost authority on the evolution of coal. Significant contributions of the evolution of oil and on isostasy came from his pen. His publications number upwards of two hundred titles.

To his numerous scientific confreres David White was always an inspiration. Ever willing to share his encyclopedic knowledge, he was a joy to the ernest student. To anyone who sought his counsel he would devote time without stint. His welcoming smile and courteous demeanor and his enthusiasm made him a welcome addition to any gathering. Although many offers came to enter the commercial field at much larger salaries than that he received from the government, he was never tempted to leave the Survey. He preferred a position in which he could pursue truth for its own sake rather than one that would yield larger economic results.

Dr. White received during his life time gratifying recognition of the high place he held in the esteem of his fellows. He was given honorary degrees by Cincinnati and Rochester Universities and Williams College. He was a member of the National Academy of Sciences, being its home secretary from 1923 to 1927, and later a vice president. He was a member of the Paleontological, Geological and Botanical Societies of America, the American Academy of Arts and Sciences, the American Philosophical, and the Washington Academy of Sciences. In 1909 he was vice president of the Paleontological Society, in 1920 president of the Geological Society of America. From 1924 to 1927 he was chairman of the division of Geology and Geography of the National Research Council. Two of the principal medals of the National Academy were bestowed upon him. He received the Penrose medal of the Society of Economic Geologists and the Boverton Redwood Medal of the Institute of Petroleum Geologists of London. He was an honorary member of the Geological Societies of Belgium and China.

In 1886 he married Mary Elizabeth Houghton of Worcester, Massachusetts. They had no children. Early in 1931 he had a slight paralytic shock from which he recovered almost entirely, with mental ability unimpaired. He succumbed to what was probably a second stroke, passing away quietly in his sleep during the night of February 6, 1935.

HERVEY W. SHIMER.

ERNEST HENRY WILSON[1] (1876–1930)

Fellow in Class II, Section 3, 1929

Ernest Henry Wilson was born at Chipping Campden in Gloucestershire, England, on February 15, 1876, the eldest son of Henry and Annie (Curtis) Wilson. After leaving school, he entered the nurseries of Messrs. Hewitt at Solihull, Warwickshire, as an apprentice. In 1892, he obtained a position in the Birmingham Botanic Garden and studied at the same time in the Technical School at Birmingham where he won the Queen's prize in botany. In 1897, he entered the Royal Botanic Gardens at Kew which gave him the opportunity to attend botanical lectures and to study the rich collections of living plants. This increased his interest in botany, so that he decided to enter the Royal College of Science at South Kensington with the intention of becoming a teacher of botany.

About that time, the nursery firm of Veitch and Sons asked the director of Kew Gardens to recommend a man to collect seeds and living plants in China. The choice fell on Wilson, and he left England in April 1899 for China, by the way of Boston and San Francisco, paying on this occasion a visit to the Arnold Arboretum. He landed in Hongkong and went first to Yunnan to meet Dr. A. Henry, who had been for many years a successful collector of plants, and who gave him all possible advice and instruction for his work. He returned to Hongkong and traveled from Shanghai up to Ichang. With Ichang as his headquarters, he collected in Hupeh during 1900 and 1901 a large number of seeds and living plants, many of them new to cultivation and of great horticultural value, and also much herbarium material.

In April, 1902, he returned to England and married Ellen Ganderton, of Edgbaston, Warwickshire. They had one daughter, Muriel Primrose.

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[1] See also the biographical notice in *Journ. Arnold Arboretum*, 11, 1930, 181–192, pl.

As he had been so successful in his collecting, he was sent on a second expedition to China and collected during 1903 and 1904, chiefly in Szechuan. After his return to England, he assisted at Kew in the arrangement of his herbarium collections, and in 1906, he accepted a position as botanical assistant at the Imperial Institute in London. The success of Wilson as a collector attracted the attention of Professor C. S. Sargent, and he induced Wilson to undertake for the Arnold Arboretum another expedition to China. In 1907, he collected chiefly in Hupeh, and in 1908 in Szechuan, returning in the spring of 1909. As the conifers in western China did not bear cones in 1908, he was sent on his fourth Chinese expedition chiefly to secure cones and seeds of these plants. It was on this expedition that he met with a serious accident; following a narrow trail on a steep slope, the party was surprised by a landslide, and a bouncing rock broke Wilson's right leg in two places. He had to be carried with a temporarily bandaged leg for three days before he reached the nearest mission station where he could be cared for by physicians, but as infection had set in, his recovery took a long time. In March, 1911, he returned to the Arnold Arboretum where he remained until the end of 1913 working up his collections and preparing jointly with the writer an account of his collections under the title "Plantae Wilsonianae" edited in three volumes by C. S. Sargent. In 1915, he visited Japan, and after his return, he continued his work on "Plantae Wilsonianae," of which the last part was issued in January, 1917. Shortly after, he started on his sixth voyage to the Far East and collected during 1917 and 1918 in Korea, Japan and Formosa.

In April, 1919, Wilson was appointed Assistant Director of the Arnold Arboretum, and in July, 1920, he started on a tour to Australia, New Zealand, India, and Central and South Africa, returning to the Arnold Arboretum in August, 1922. In April, 1927, after the death of Professor C. S. Sargent, he was appointed Keeper of the Arnold Arboretum. On October 15, 1930, Wilson died together with his wife in an automobile accident, which occurred near Worcester, Mass., when returning from a visit to their daughter in Geneva, N. Y.

Wilson was a frequent contributor to horticultural and botanical periodicals and published a number of important horticultural and botanical books; he wrote of his experiences in China in "A Naturalist in Western China," "Plant Hunting," and "China, Mother of

Gardens"; he dealt with ornamental plants, chiefly trees and shrubs, in "Aristocrats of the Garden," "More Aristocrats of the Garden," "Aristocrats of Trees," and "America's Greatest Garden;" more strictly botanical are "Cherries of Japan," "The Conifers and Taxads of Japan," "A Monograph of Azaleas (with A. Rehder)," "The Lilies of Eastern Asia," and his contributions to "Plantae Wilsonianae."

Many honors were bestowed upon Wilson. He received several gold medals for his services to horticulture. In 1916, the honorary degree of A.M. was conferred on him by Harvard University, and the honorary degree of Sc.D. by Trinity College of Hartford, Conn., in 1930. He was elected Fellow of the American Academy of Arts and Sciences and honorary member of several horticultural societies, and also was a member of other scientific and horticultural societies. A new genus of Hamamelidaceae from China, Sinowilsonia, was named in his honor and about sixty species and varieties of Chinese plants bear his name.

Wilson's chief contribution to horticulture and botany lies in his exploration of China where he spent most of his time between 1899 and 1911. He was a born plant collector; endowed with strong physique, robust health, indomitable will power and a deep love of plants, he succeeded in collecting and introducing into cultivation a very large number of plants. He introduced more than a thousand species previously unknown to cultivation, and collected about 16,000 numbers of herbarium specimens, many of them new to science, with numerous duplicates, so that now his specimens are found in all important herbaria throughout the world, and his plants have spread to all gardens of temperate and subtropical regions.

ALFRED REHDER.

JAY BACKUS WOODWORTH (1865–1925)

Fellow in Class II, Section 1, 1900

On the fourth of August 1925 Jay Backus Woodworth died. Woodworth was born on January 2, 1865, at Newfield, New York, not far from Ithaca. His father, Allen Beach Woodworth, was a Baptist minister of old colonial descent. His mother, Amanda Ette Smith, was also a New Englander. Governor Winthrop was one of his distinguished ancestors, and other ancestors were prominent in the Indian Wars and the Revolution.

Brought up on a farm in a country noted for its geological formations Woodworth had a good opportunity to find fossils. He had Dana's *Textbook of Geology* and was able with that, to find the names of many of his specimens. There was one fossil that he could not identify so he wrote to Dana and also sent the fossil. Dana, much to his surprise, answered his letter in a very friendly way and told him he had discovered a new species. Woodworth told me that on that day he decided to become a geologist.

First it was necessary to earn money for his education, so when he finished high school he went to New York City and found employment as a clerk in the office of the New York Life Insurance Company. Later on he went to Boston and entered the service of the Edison Electric Company. Shortly after this he was made assistant manager of the company. He was now on the way toward financial success, but the call of geology was too strong, and in the fall of 1890 at the age of twenty-five, he entered the Lawrence Scientific School, took his degree of Bachelor of Science in 1894, and thereafter for years was Shaler's valuable assistant until Shaler's death. This was the only degree he ever received. However, his honors later in life were many.

Although a geologist of the old school, like Dana and Shaler, his work covered three main fields; glacial geology, structural geology, and seismology. His knowledge of the history of the science of geology was as profound as that of any man in America.

In glacial geology it may be said without exaggeration, that he did more than any man in New England. Chamberlin, Leverett, Salisbury and Taylor did more in the Middle West, but in the East no one began to know as much as Woodworth. His solution of the structural puzzle of Martha's Vineyard alone is enough to put him in the front rank of glacial and structural geologists. His classification of glacial deposits is also a classic. As important as these works, however, was his great work on ancient water levels of the Hudson and Champlain valleys, which he finished in 1905.

In 1908 Woodworth went to South America on the first Shaler Memorial Expedition. It was fitting that Shaler's righthand man should be the first to have this honor. During this trip Woodworth proved what others had suspected, namely, that the big conglomerate of Late Carboniferous or Permian age in Brazil was a tillite, a consolidated till of glacial origin.

Probably the most comprehensive work Woodworth did in glacial geology was in cooperation with Dr. Edward Wigglesworth, on the glacial geology of southeastern New England, including Martha's Vineyard, Block Island, Nantucket, Cape Cod, Plymouth region and Buzzard's Bay region. The manuscript of this paper, handed in in 1919, was considered too bulky for publication by the United States Geological Survey. Finally the paper was published by the Museum of Comparative Zoölogy in 1934, fifteen years after Woodworth and Wigglesworth finished it.

Woodworth's first important work in structural and stratigraphical geology was the publication of the *Geology of the Richmond Basin, Virginia* in 1899. This work was done jointly with Shaler. The same year he published with Shaler the *Geology of the Narragansett Basin.*

Woodworth's knowledge of the structure of North America was profound. In 1899, Shaler, who had always wanted a summer school of geology in the Rockies, organized the first course in geology in Montana. He put Woodworth in charge. It was my privilege to go along as an undergraduate student. Woodworth conducted this course for twelve different summers, and as a result of it obtained a theory of mountain building which he taught his students in the course on the geology of North America.

One little paper Woodworth published describes sand-blasted pebbles. In 1894, while on the Cape, he found that pebbles favorably situated are shaped in definite ways and polished by the wind. Woodworth called such pebbles "Glyptoliths" and since his discovery they have been found in a great many places all over the earth.

Woodworth's seismological work was more recent. A Bosch-Omori instrument, imported from Germany, and the latest word in seismographs at the time, was installed in the Geological Museum early in 1908. Woodworth accomplished a great deal with this instrument and at the time of his death ranked the highest in America in accuracy of timing and in estimating distances of quakes. He was the first to call attention to the greater prevalence of earthquakes when the sun and moon were over certain meridians. He was also the first to discover that earthquakes take place in New England from north to south. That is if there is a quake near Montreal the next quake can be looked for farther south, and the cycle finished in the south then starts all over again in the north.

Woodworth made an important discovery on the seismograph which has been noted by Charles F. Brooks, Secretary of the American Meteorological Society. Brooks says in part: "His approach to meteorology was perhaps unique. It was through his seismograph. Shortly after he established the Harvard Seismographic Station, in 1908, he found that the ground tilted more or less strongly in the direction of highest atmospheric pressure." The writer asked Woodworth why he did not publish his discovery of the tilting of the ground under high and low atmospheric pressures, and Woodworth said: "Another fellow found it too, Sayles." The "other fellow" was F. Napier Denison, then in charge of the seismograph at Victoria, B. C. He had as much right to claim credit for the discovery as Denison. Only a few knew that Woodworth made this discovery independently.

In 1906, while I was with him near Saratoga doing field work, he received an invitation to take the place of the late I. C. Russell, head of geology at the University of Michigan. This was a tempting offer. He sent the letter to President Eliot but was advised by Eliot to stay at Harvard, and that his promotion was assured.

Woodworth's love of old as well as new books was well known. He made a specialty of old editions of geological books, and his collections with their many first editions are now the property of the Division of Geology and Geography at Harvard. He had over fifty editions of Herodotus. He not only bought old books and prints but he was familiar with their contents. After he left college he took up Greek as a recreation, and was able to read it very well, as well as Latin. He was even well versed in the reading of Egyptian hieroglyphics as the inscription in the seismographic station attests. He translated it as follows: "When thy messenger comes to take thee be thou found by him ready. Follow thou silence."

As a lecturer Woodworth was not a success in large classes, but in conference with students he was most stimulating and helpful. There is a long list of able American geologists today, who owe their foundation, thoroughness, and perhaps their success more to J. B. Woodworth than to anyone else.

Woodworth married Genevieve Downs in 1891. Ethel Woodworth, the only child, is a graduate of Radcliffe. Woodworth's last year was full of pain. He suffered a great deal from cardiac asthma. Late in the fall of 1924 he was advised to go to Florida. He went to Vero on the east coast and his stay during the winter months benefitted him to some extent. He returned in April apparently improved, but soon began to grow worse and the end came much sooner than expected, on August 4, 1925.

Robert W. Sayles.

American Academy of Arts and Sciences.

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CLASS I—*Mathematical and Physical Sciences*—212

SECTION 1—*Mathematics and Astronomy*—53

21	Charles Greeley Abbot	Washington, D. C.
32	Clarence Raymond Adams	Providence, R. I.
22	Walter Sydney Adams	Pasadena, Cal.
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17	Raymond Clare Archibald	Providence, R. I.
32	Albert Arnold Bennett	Providence, R. I.
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15	Philip Fox	Evanston, Ill.

92	Fabian Franklin	New York, N. Y.
30	Philip Franklin	Belmont
24	William Caspar Graustein	Cambridge
32	Einar Hille	New Haven, Conn.
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13	Edward Vermilye Huntington	Cambridge
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29	Marston Morse	Princeton, N. J.
19	Forest Ray Moulton	Chicago, Ill.
18	Henry Bayard Phillips	Belmont
[83] 99	William Henry Pickering	Mandeville, Jamaica, B. W. I.
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14	Roland George Dwight Richardson	Providence, R. I.
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31	George Rutledge	Belmont
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20	Harlow Shapley	Cambridge
09	Vesto Melvin Slipher	Flagstaff, Ariz.
17	Frederick Slocum	Middletown, Conn.
19	Virgil Snyder	Ithaca, N. Y.
21	Joel Stebbins	Madison, Wis.
27	Harlan True Stetson	Waban
33	Marshall Harvey Stone	Cambridge
30	Dirk Jan Struik	Belmont
28	Jacob David Tamarkin	Providence, R. I.
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29	Joseph Leonard Walsh	Cambridge
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32	David Vernon Widder	Cambridge
12	Frederick Shenstone Woods	Newton Center

Class I, Section II—*Physics*—63

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11	Joseph Sweetman Ames	Baltimore, Md.
21	Samuel Jackson Barnett	Los Angeles, Cal.
12	Percy William Bridgman	Cambridge
26	Walter Guyton Cady	Middletown, Conn.
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12	Daniel Frost Comstock	Brookline
15	William David Coolidge	Schenectady, N. Y.
34	Franzo Hazlett Crawford	Cambridge
13	Henry Crew	Evanston, Ill.
11	Harvey Nathaniel Davis	Hoboken, N. J.
29	Clinton Joseph Davisson	New York, N. Y.
12	Arthur Louis Day	Washington, D. C.
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97	Harry Manley Goodwin	Brookline
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31	George Russell Harrison	Belmont
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17	Gordon Ferrie Hull	Hanover, N. H.
14	Charles Clifford Hutchins	Brunswick, Me.
21	Frederic Eugene Ives	Philadelphia, Pa.
14	James Edmund Ives	Washington, D. C.
22	Edwin Crawford Kemble	Cambridge
13	Norton Adams Kent	Newton Center
97	Frank Arthur Laws	Brookline
99	Henry Lefavour	Boston
31	Robert Bruce Lindsay	Providence, R. I.
01	Theodore Lyman	Brookline

34	Louis Williams McKeehan	New Haven, Conn.
14	Ernest George Merritt	Ithaca, N. Y.
14	Dayton Clarence Miller	Cleveland, O.
14	Robert Andrews Millikan	Pasadena, Cal.
34	Harry Rowe Mimno	Cambridge
11	Harry Wheeler Morse	Stanford University, Cal.
34	Philip McCord Morse	Cambridge
01	Edward Leamington Nichols	Ithaca, N. Y.
07	Charles Ladd Norton	Boston
31	Otto Oldenberg	Cambridge
34	Leigh Page	New Haven, Conn.
07	George Washington Pierce	Cambridge
35	Floyd Karker Richtmyer	Ithaca, N. Y.
16	Frederick Albert Saunders	Cambridge
27	John Clarke Slater	Cambridge
96	John Stone Stone	San Diego, Cal.
12	Maurice DeKay Thompson	Brookline
88	Elihu Thomson	Swampscott
28	Manuel Sandoval Vallarta	Brookline
35	Robert Jemison Van de Graaff	Cambridge
34	John Hasbrouck Van Vleck	Cambridge
35	Bertram Eugene Warren	Cambridge
18	David Locke Webster	Palo Alto, Cal.
11	Edwin Bidwell Wilson	Brookline
13	Robert Williams Wood	Baltimore, Md.
17	John Zeleny	New Haven, Conn.

CLASS I, SECTION III—*Chemistry*—50

26	Roger Adams	Urbana, Ill.
13	Wilder Dwight Bancroft	Ithaca, N. Y.
07	Gregory Paul Baxter	Cambridge
29	James Alexander Beattie	Belmont
19	Arthur Alphonzo Blanchard	Brookline
14	Marston Taylor Bogert	New York, N. Y.
11	William Crowell Bray	Berkeley, Cal.
12	Russell Henry Chittenden	New Haven, Conn.
24	James Bryant Conant	Cambridge
23	Tenney Lombard Davis	Norwell

09	Henry Fay	Brookline
33	Louis Frederick Fieser	Waltham
15	George Shannon Forbes	Cambridge
21	Edward Curtis Franklin	Palo Alto, Cal.
28	Louis John Gillespie	Somerville
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99	Arthur Amos Noyes	Pasadena, Cal.
13	William Albert Noyes	Urbana, Ill.
31	William Albert Noyes, Jr.	Providence, R. I.
14	Samuel Cate Prescott	Brookline
79	Robert Hallowell Richards	Jamaica Plain
14	Martin André Rosanoff	Pittsburgh, Pa.
28	George Scatchard	Cambridge
32	Walter Cecil Schumb	East Milton
15	Miles Standish Sherrill	Brookline
20	Harry Monmouth Smith	Brookline
34	Leighton Bruerton Smith	Beverly
14	Julius Oscar Stieglitz	Chicago, Ill.
22	Richard Chace Tolman	Pasadena, Cal.
11	Willis Rodney Whitney	Schenectady, N. Y.
19	Robert Seaton Williams	Belmont

19	Alpheus Grant Woodman	Watertown
34	David Elbridge Worrall	Tufts College

Class I, Section IV—*Technology and Engineering*—46

06	Comfort Avery Adams	Belmont
33	Harold Kilbrith Barrows	Winchester
31	Charles Harold Berry	Belmont
14	William Hubert Burr	New Canaan, Conn.
25	Vannevar Bush	Belmont
02	Harry Ellsworth Clifford	Newton Center
34	Otto Gustav Colbiornsen Dahl	Brookline
34	Chester Laurens Dawes	Cambridge
34	Jacob Pieter Den Hartog	Wellesley Hills
20	Theodore Harwood Dillon	Brookline
27	Philip Drinker	Newton Center
22	Gano Dunn	New York, N. Y.
21	William Frederick Durand	Palo Alto, Cal.
27	Gordon Maskew Fair	Cambridge
19	Frederic Harold Fay	Boston
32	Glennon Gilboy	Lincoln
32	Albert Haertlein	Watertown
14	John Hays Hammond	New York, N. Y.
23	William Hovgaard	Brooklyn, N. Y.
34	Jerome Clarke Hunsaker	Boston
23	James Robertson Jack	Watertown
11	Dugald Caleb Jackson	Cambridge
30	Frank Baldwin Jewett	New York, N. Y.
01	Lewis Jerome Johnson	Cambridge
05	Arthur Edwin Kennelly	Cambridge
32	Ralph Restieaux Lawrence	Belmont
23	William Henry Lawrence	Jamaica Plain
21	Charles Thomas Main	Winchester
12	Lionel Simeon Marks	Cambridge
34	Edward Leyburn Moreland	Wellesley
33	Arthur Edwin Norton	Cambridge
20	Frederick Law Olmsted	Brookline
15	Charles Francis Park	Taunton
28	Langdon Pearse	Chicago, Ill.

13	Harold Pender	Philadelphia, Pa.
30	Greenleaf Whittier Pickard	Newton Center
30	George Edmond Russell	Bedford
03	Albert Sauveur	Cambridge
01	Henry Lloyd Smyth	Watertown
14	Charles Milton Spofford	Brookline
28	John F. Stevens	Baltimore, Md.
23	Edward Pearson Warner	New York, N. Y.
29	Arthur Edward Wells	New York, N. Y.
27	Robert Spurr Weston	Brookline
33	Frank Edward Winsor	West Newton
15	Joseph Ruggles Worcester	Waltham

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15	Wallace Walter Atwood	Worcester
21	Norman Levi Bowen	Washington, D. C.
16	Isaiah Bowman	Baltimore, Md.
33	Charles Franklin Brooks	Milton
29	Kirk Bryan	Cambridge
33	Frank Morton Carpenter	Newtonville
93	Henry Helm Clayton	Canton
09	Reginald Aldworth Daly	Cambridge
35	Oliver Lanard Fassig	San Juan, P. R.
34	Sterling Price Fergusson	Milton
18	William Ebenezer Ford	New Haven, Conn.
17	James Walter Goldthwait	Hanover, N. H.
14	Louis Caryl Graton	Cambridge
17	Herbert Ernest Gregory	Honolulu, T. H.
21	William Jackson Humphreys	Washington, D. C.
16	Ellsworth Huntington	New Haven, Conn.
95	Robert Tracy Jackson	Peterborough, N. H.
02	Thomas Augustus Jaggar	Honolulu, T. H.
08	Douglas Wilson Johnson	New York, N. Y.
21	Arthur Keith	Washington, D. C.
10	Alfred Church Lane	Cambridge
25	Esper Signius Larsen, Jr.	Belmont

15	Andrew Cowper Lawson	Berkeley, Cal.
16	Charles Kenneth Leith	Madison, Wis.
12	Waldemar Lindgren	Brookline
17	Frederic Brewster Loomis	Amherst
17	Alexander George McAdie	Hampton, Va.
31	George Francis McEwen	La Jolla, Cal.
27	Donald Hamilton McLaughlin	Cambridge
25	Kirtley Fletcher Mather	Newton Center
26	Edward Bennett Mathews	Baltimore, Md.
35	Warren Judson Mead	Cambridge
21	John Campbell Merriam	Washington, D. C.
17	William John Miller	Los Angeles, Cal.
32	Frederick Kuhne Morris	Cambridge
34	Walter Harry Newhouse	Medford
03	Charles Palache	Cambridge
17	Percy Edward Raymond	Lexington
22	Austin Flint Rogers	Palo Alto, Cal.
34	Carl-Gustaf Arvid Rossby	Jamaica Plain
15	Robert Wilcox Sayles	Chestnut Hill
19	Waldemar Theodore Schaller	Washington, D. C.
15	Charles Schuchert	New Haven, Conn.
12	William Berryman Scott	Princeton, N. J.
11	Hervey Woodburn Shimer	Hingham
25	Frank Bursley Taylor	Fort Wayne, Ind.
17	Thomas Wayland Vaughan	La Jolla, Cal.
08	Charles Hyde Warren	New Haven, Conn.
14	Herbert Percy Whitlock	New York, N. Y.
35	Derwent Stainthorpe Whittlesey	Cambridge
15	Bailey Willis	Palo Alto, Cal.
95	John Eliot Wolff	Pasadena, Cal.
15	Frederick Eugene Wright	Washington, D. C.

CLASS II, SECTION II—*Botany*—36

30	LeRoy Abrams	Stanford University, Cal.
11	Oakes Ames	North Easton
34	Edgar Anderson	St. Louis, Mo.
23	Joseph Charles Arthur	Lafayette, Ind.
15	Irving Widmer Bailey	Cambridge

00	Liberty Hyde Bailey	Ithaca, N. Y.
21	Edward Wilber Berry	Baltimore, Md.
98	Douglas Houghton Campbell	Palo Alto, Cal.
14	George Perkins Clinton	New Haven, Conn.
16	Bradley Moore Davis	Ann Arbor, Mich.
35	Bernard Ogilvie Dodge	New York, N. Y.
11	Edward Murray East	Jamaica Plain
21	Rollins Adams Emerson	Ithaca, N. Y.
12	Alexander William Evans	New Haven, Conn.
29	Joseph Horace Faull	Cambridge
00	Merritt Lyndon Fernald	Newton
11	Robert Almer Harper	New York, N. Y.
98	John George Jack	East Walpole
28	Willis Linn Jepson	Berkeley, Cal.
27	Ivan Murray Johnston	Brookline
34	Donald Forsha Jones	New Haven, Conn.
21	Jacob Goodale Lipman	New Brunswick, N. J.
14	Burton Edward Livingston	Baltimore, Md.
21	Elmer Drew Merrill	Cambridge
10	Winthrop John Vanleuven Osterhout	New York, N. Y.
27	George James Peirce	Palo Alto, Cal.
14	Alfred Rehder	Jamaica Plain
30	Karl Sax	Jamaica Plain
16	William Albert Setchell	Berkeley, Cal.
34	Edmund Ware Sinnott	New York, N. Y.
34	Gilbert Morgan Smith	Stanford University, Cal.
23	Elvin Charles Stakman	St. Paul, Minn.
92	William Trelease	Urbana, Ill.
31	Charles Alfred Weatherby	Cambridge
22	William Henry Weston, Jr.	Cambridge
32	Ralph Hartley Wetmore	Belmont

CLASS II, SECTION III—*Zoology and Physiology*—71

22	Nathan Banks	Jamaica Plain
16	Thomas Barbour	Boston
33	Philip Bard	Baltimore, Md.
09	Francis Gano Benedict	Boston
1	Henry Bryant Bigelow	Concord

14	Robert Payne Bigelow	Brookline
35	Charles Henry Blake	Cambridge
20	William T. Bovie	Bar Harbor, Me.
24	Edward Allen Boyden	Minneapolis, Minn.
16	John Lewis Bremer	Boston
15	Charles Thomas Brues	Jamaica Plain
28	John Wymond Miller Bunker	Belmont
06	Walter Bradford Cannon	Cambridge
22	Thorne Martin Carpenter	Boston
00	William Ernest Castle	Belmont
14	Charles Value Chapin	Providence, R. I.
29	Lemuel Roscoe Cleveland	Jamaica Plain
26	Edwin Joseph Cohn	Cambridge
14	Edwin Grant Conklin	Princeton, N. J.
23	Manton Copeland	Brunswick, Me.
27	William John Crozier	Cambridge
17	Joseph Augustine Cushman	Sharon
35	J[ohn] Frank[lin] Daniel	Berkeley, Cal.
95	Charles Benedict Davenport	Cold Spring Harbor, N. Y.
29	Hallowell Davis	Belmont
33	Alden Benjamin Dawson	Belmont
25	Samuel Randall Detwiler	New York, N. Y.
25	Herbert McLean Evans	Berkeley, Cal.
30	Henry Clinton Fall	Tyngsboro
34	Cyrus Hartwell Fiske	Belmont
15	Alexander Forbes	Milton
34	John Farquhar Fulton	New Haven, Conn.
31	William King Gregory	New York, N. Y.
29	Joseph Grinnell	Berkeley, Cal.
89	Samuel Henshaw	Cambridge
29	Leigh Hoadley	Cambridge
34	Hudson Hoagland	Worcester
24	Samuel Jackson Holmes	Berkeley, Cal.
28	Roy Graham Hoskins	Waban
13	Leland Ossian Howard	Washington, D. C.
14	Herbert Spencer Jennings	Baltimore, Md.
13	Charles Atwood Kofoid	Berkeley, Cal.
16	Frederic Thomas Lewis	Waban

33	Frank Rattray Lillie	Chicago, Ill.
14	Ralph Stayner Lillie	Chicago, Ill.
17	Richard Swann Lull	New Haven, Conn.
84	Edward Laurens Mark	Cambridge
15	Albert Davis Mead	Providence, R. I.
27	Axel Leonard Melander	New York, N. Y.
35	Karl Friedrich Meyer	San Francisco, Cal.
21	Gerrit Smith Miller	Washington, D. C.
28	Thomas Hunt Morgan	Pasadena, Cal.
14	Herbert Vincent Neal	Tufts College
95	George Howard Parker	Cambridge
19	Raymond Pearl	Baltimore, Md.
15	John Charles Phillips	Wenham
21	Henry Augustus Pilsbry	Philadelphia, Pa.
27	Frederick Haven Pratt	Wellesley Hills
09	Herbert Wilbur Rand	Belmont
32	David Rapport	Cambridge
23	Alfred Clarence Redfield	Milton
34	Alfred Newton Richards	Philadelphia, Pa.
34	Oscar Riddle	Cold Spring Harbor, N. Y.
13	William Emerson Ritter	Berkeley, Cal.
25	Alexander Grant Ruthven	Ann Arbor, Mich.
16	Percy Goldthwait Stiles	Newtonville
15	Arthur Wisswald Weysse	Boston
09	William Morton Wheeler	Boston
02	Edmund Beecher Wilson	New York, N. Y.
15	Frederick Adams Woods	Rome, Italy
33	Jeffries Wyman, Jr.	Chestnut Hill

CLASS II, SECTION IV—*Medicine and Surgery*—55

32	Joseph Charles Aub	Belmont
29	James Bourne Ayer	Milton
(28) 32	Franklin Greene Balch	Boston
31	George Blumer	New Haven, Conn.
21	Charles Macfie Campbell	Cambridge
19	Alexis Carrel	New York, N. Y.
31	William Bosworth Castle	Brookline
30	David Cheever	Boston

13	Henry Asbury Christian	Brookline
21	Rufus Cole	New York, N. Y.
14	Harvey Cushing	New Haven, Conn.
32	Elliott Carr Cutler	Brookline
31	Eugene Floyd DuBois	New York, N. Y.
33	Reginald Fitz	Brookline
11	Simon Flexner	New York, N. Y.
27	James Lawder Gamble	Brookline
22	Joseph Lincoln Goodale	Boston
18	Robert Battey Greenough	Brookline
21	Ross Granville Harrison	New Haven, Conn.
27	Percy Rogers Howe	Belmont
21	William Henry Howell	Baltimore, Md.
33	Edgar Erskine Hume	Washington, D. C.
15	Reid Hunt	Boston
34	Henry Jackson, Jr.	Chestnut Hill
12	Elliott Proctor Joslin	Boston
23	Roger Irving Lee	Brookline
29	Edwin Allen Locke	Williamstown
28	Warfield Theobald Longcope	Baltimore, Md.
32	Fred Bates Lund	Newton
33	George Burgess Magrath	Boston
13	Frank Burr Mallory	Brookline
21	William James Mayo	Rochester, Minn.
34	Leroy Matthew Simpson Miner	Newtonville
26	George Richards Minot	Brookline
28	William Lorenzo Moss	Augusta, Ga.
28	John Howard Mueller	West Roxbury
25	Robert Bayley Osgood	Boston
27	Joseph Hershey Pratt	Boston
35	Tracy Jackson Putnam	Brookline
34	William Carter Quinby	Brookline
34	Arthur Hiler Ruggles	Providence, R. I.
27	Andrew Watson Sellards	Boston
33	George Cheever Shattuck	Brookline
30	Torald Hermann Sollmann	Cleveland, Ohio
21	Charles Wardell Stiles	Washington, D. C.
14	Richard Pearson Strong	Boston

30	Fritz Bradley Talbot	Brookline
14	Ernest Edward Tyzzer	Wakefield
14	Frederick Herman Verhoeff	Brookline
27	Joseph Treloar Wearn	Cleveland, Ohio
33	Soma Weiss	Cambridge
25	Benjamin White	New York, N. Y.
02	Francis Henry Williams	Boston
12	Simeon Burt Wolbach	South Sudbury
23	Hans Zinsser	Boston

CLASS III—*The Social Arts*—137

SECTION I—*Jurisprudence*—33

31	George Weston Anderson	Boston
(24) 32	Francis Noyes Balch	Jamaica Plain
06	Joseph Henry Beale	Cambridge
33	Harry Augustus Bigelow	Chicago, Ill.
33	Henry Wolf Biklé	Philadelphia, Pa.
33	Benjamin Nathan Cardozo	Washington, D. C.
33	John Dickinson	Washington, D. C.
31	Fred Tarbell Field	Newton
32	Felix Frankfurter	Cambridge
30	Thomas Hovey Gage	Worcester
33	Theodore Francis Green	Providence, R. I.
32	Walter Perley Hall	Fitchburg
33	Learned Hand	New York, N. Y.
18	Charles Evans Hughes	Washington, D. C.
31	Nathan Isaacs	Cambridge
32	Eldon Revare James	Cambridge
21	Frederick Lawton	Boston
32	Sayre Macneil	Azusa, Cal.
32	Calvert Magruder	Cambridge
31	William DeWitt Mitchell	New York, N. Y.
31	Edmund Morris Morgan	Arlington
31	Herbert Parker	South Lancaster
01	George Wharton Pepper	Philadelphia, Pa.
11	Roscoe Pound	Watertown
12	Elihu Root	New York, N. Y.

12	Arthur Prentice Rugg	Worcester
32	Francis Bowes Sayre	Washington, D. C.
21	Austin Wakeman Scott	Cambridge
35	James Brown Scott	Washington, D. C.
33	Harlan Fiske Stone	Washington, D. C.
32	Edward Sampson Thurston	Cambridge
14	Eugene Wambaugh	Cambridge
(28) 32	Edmund Allen Whitman	Cambridge

CLASS III, SECTION II—*Government, International Law, and Diplomacy*—26

33	George Hubbard Blakeslee	Worcester
33	Edwin Montefiore Borchard	New Haven, Conn.
32	William Richards Castle, Jr.	Washington, D. C.
32	Joseph Perkins Chamberlain	New York, N. Y.
33	Robert Treat Crane	New York, N. Y.
35	Tyler Dennett	Williamstown
31	Sidney Bradshaw Fay	Cambridge
27	William Cameron Forbes	Norwood
34	Edgar Stephenson Furniss	New Haven, Conn.
32	Joseph Clark Grew	Tokyo, Japan
35	Charles Grove Haines	Los Angeles, Cal.
16	Albert Bushnell Hart	Cambridge
27	Arthur Norman Holcombe	Cambridge
31	Manley Ottmer Hudson	Cambridge
32	Philip Carryl Jessup	New York, N. Y.
97	Abbott Lawrence Lowell	Boston
18	William MacDonald	New York, N. Y.
32	Charles Edward Merriam	Chicago, Ill.
32	Ogden Livingston Mills	New York, N. Y.
19	John Bassett Moore	New York, N. Y.
13	William Bennett Munro	Pasadena, Cal.
27	Westal Woodbury Willoughby	Washington, D. C.
32	William Franklin Willoughby	Washington, D. C.
14	George Grafton Wilson	Cambridge
27	Quincy Wright	Chicago, Ill.
33	Henry Aaron Yeomans	Cambridge

Class III, Section III—*Economics and Sociology*—50

33	Harold Hitchings Burbank	Cambridge
16	John Bates Clark	New York, N. Y.
34	John Maurice Clark	Westport, Conn.
28	Arthur Harrison Cole	Cambridge
31	Melvin Thomas Copeland	Cambridge
31	William Leonard Crum	Cambridge
32	William James Cunningham	Cambridge
34	Winthrop More Daniels	New Haven, Conn.
21	Clive Day	New Haven, Conn.
13	Davis Rich Dewey	Cambridge
32	Arthur Stone Dewing	Newton
32	Wallace Brett Donham	Boston
34	John Franklin Ebersole	Belmont
12	Irving Fisher	New Haven, Conn.
31	James Ford	Cambridge
34	Ralph Evans Freeman	Cambridge
13	Edwin Francis Gay	Cambridge
33	Sheldon Glueck	Cambridge
34	Robert Murray Haig	New York, N. Y.
32	Henry Wyman Holmes	Cambridge
34	Edwin Walter Kemmerer	Princeton, N. J.
34	Frank Hyneman Knight	Chicago, Ill.
34	Robert Morison MacIver	New York, N. Y.
32	Walter Wallace McLaren	Williamstown
32	Leon Carroll Marshall	Washington, D. C.
33	Edward Sagendorph Mason	Cambridge
34	Richard Stockton Meriam	South Lincoln
34	Harry Alvin Millis	Washington, D. C.
32	Frederick Cecil Mills	New York, N. Y.
31	Wesley Clair Mitchell	New York, N. Y.
34	Arthur Eli Monroe	Cambridge
32	Harold Glenn Moulton	Washington, D. C.
34	Edwin Griswold Nourse	Washington, D. C.
32	William Fielding Ogburn	Chicago, Ill.
33	Robert Ezra Park	Chicago, Ill.
28	Warren Milton Persons	New York, N. Y.
32	Leo S. Rowe	Washington, D. C.

33 Josef Alois Schumpeter	Cambridge
32 Carl Snyder	New York, N. Y.
31 Pitirim Alexandrovich Sorokin	Winchester
31 Oliver Mitchell Wentworth Sprague	Cambridge
[89] 01 Frank William Taussig	Cambridge
34 Frederick John Teggart	Berkeley, Cal.
33 William Isaac Thomas	New York, N. Y.
31 Donald Skeele Tucker	Belmont
33 Abbott Payson Usher	Cambridge
34 Jacob Viner	Chicago, Ill.
32 John Henry Williams	Cambridge
34 Leo Wolman	Washington, D. C.
34 Carle Clark Zimmerman	Winchester

Class III, Section IV—*Administration and Affairs*—28

(25) 32 Charles Francis Adams	Concord
(25) 32 Charles Foster Batchelder	Cambridge
24 Ingersoll Bowditch	Jamaica Plain
(26) 32 John Albert Cousens	Tufts College
32 Henry Sturgis Dennison	Framingham
(28) 32 William Lusk Webster Field	Milton
16 Frank Johnson Goodnow	Baltimore, Md.
35 Jerome Davis Greene	Cambridge
(24) 32 Francis Russell Hart	Boston
(28) 32 Edward Jackson Holmes	Boston
34 Matt Bushnell Jones	Newton Center
34 Henry Plimpton Kendall	Walpole
(27) 32 Nathaniel Thayer Kidder	Milton
32 Thomas William Lamont	New York, N. Y.
34 Clarence Cook Little	Bar Harbor, Me.
33 James Vance May	Boston
(28) 31 Thomas Nelson Perkins	Westwood
(24) 32 Andrew James Peters	Jamaica Plain
02 Herbert Putnam	Washington, D. C.
(28) 32 Alfred Lawrence Ripley	Andover
34 Erwin Haskell Schell	Cambridge
35 Henry Lee Shattuck	Boston
(28) 32 Payson Smith	Brookline

33	Albert Warren Stearns	Billerica
(25) 32	Charles Henry Taylor	Boston
34	Charles Franklin Thwing	Cleveland, O.
(24) 32	Edwin Sibley Webster	Brookline
(25) 32	Benjamin Loring Young	Weston

CLASS IV—*The Humanities*—207

SECTION I—*Theology, Philosophy, and Psychology*—50

32	Michael Joseph Ahern	Weston
33	Gordon Willard Allport	Cambridge
32	James Rowland Angell	New Haven, Conn.
33	John Gilbert Beebe-Center	Swampscott
34	Edwin Garrigues Boring	Cambridge
28	Edgar Sheffield Brightman	Newton
31	Henry Addington Bruce	Cambridge
32	Leonard Carmichael	Providence, R. I.
33	J(ames) McKeen Cattell	Garrison, N. Y.
32	George Croft Cell	Reading
28	Walter Fenno Dearborn	Cambridge
18	Edmund Burke Delabarre	Providence, R. I.
24	Raymond Dodge	New Haven, Conn.
33	Curt John Ducasse	Providence, R. I.
30	William Henry Paine Hatch	Cambridge
32	William Healy	Boston
10	William Arthur Heidel	Middletown, Conn.
21	William Ernest Hocking	Cambridge
35	Clark Leonard Hull	New Haven, Conn.
33	Walter Samuel Hunter	Worcester
17	Frederick John Foakes Jackson	Englewood, N. J.
31	Truman Lee Kelley	Cambridge
28	Albert Cornelius Knudson	Cambridge
34	Kurt Koffka	Northampton
32	Karl Spencer Lashley	Belmont
13	William Lawrence	Boston
29	Clarence Irving Lewis	Lexington
33	Lee Sullivan McCollester	Tufts College
22	William McDougall	Durham, N. C.

10	Edward Caldwell Moore	Cambridge
31	Paul Elmer More	Princeton, N. J.
35	Henry Alexander Murray, Jr.	Boston
32	Arthur Darby Nock	Cambridge
32	William Cardinal O'Connell	Boston
28	Johnson O'Connor	Boston
17	Charles Edwards Park	Boston
18	Leighton Parks	London, England
18	Francis Greenwood Peabody	Cambridge
33	Carroll Cornelius Pratt	Cambridge
30	James Hugh Ryan	Omaha, Neb.
31	Henry Knox Sherrill	Boston
27	Willard Learoyd Sperry	Cambridge
29	Russell Henry Stafford	Brookline
34	Lewis Madison Terman	Stanford University, Cal.
34	Edward Lee Thorndike	New York, N. Y.
28	Henry Bradford Washburn	Cambridge
17	John Broadus Watson	New York, N. Y.
33	Frederic Lyman Wells	Newton Highlands
35	Robert Sessions Woodworth	New York, N. Y.
15	Robert Mearns Yerkes	New Haven, Conn.

CLASS IV, SECTION II—*History, Archæology, and Anthropology*—42

18	Charles McLean Andrews	New Haven, Conn.
28	James Phinney Baxter, 3d	Cambridge
23	Carl Lotus Becker	Ithaca, N. Y.
27	Robert Pierpont Blake	Cambridge
12	Franz Boas	New York, N. Y.
(25) 32	William Brooks Cabot	Boston
34	Clarence Gordon Campbell	New York, N. Y.
12	George Henry Chase	Cambridge
12	Wilberforce Eames	New York, N. Y.
21	Max Farrand	San Marino, Cal.
21	William Scott Ferguson	Cambridge
10	Worthington Chauncey Ford	Cambridge
33	Henry Thatcher Fowler	Providence, R. I.
18	Evarts Boutell Greene	New York, N. Y.
13	Charles Homer Haskins	Cambridge

19	Charles Downer Hazen	New York, N. Y.
14	Bert Hodge Hill	Athens, Greece
27	Earnest Albert Hooton	Cambridge
33	Halford Lancaster Hoskins	Tufts College
15	Aleš Hrdlička	Washington, D. C.
27	Alfred Vincent Kidder	Washington, D. C.
12	Alfred Louis Kroeber	Berkeley, Cal.
15	Kirsopp Lake	Cambridge
22	George LaPiana	Cambridge
32	Waldo Gifford Leland	Washington, D. C.
20	Charles Howard McIlwain	Belmont
14	Roger Bigelow Merriman	Cambridge
15	Samuel Eliot Morison	Boston
34	Robert Henry Pfeiffer	Cambridge
14	George Andrew Reisner	Boston
34	David Moore Robinson	Baltimore, Md.
23	Michael Ivanovich Rostovtzeff	New Haven, Conn.
33	Edward Sapir	New Haven, Conn.
27	George Sarton	Cambridge
34	Theodore Leslie Shear	Princeton, N. J.
26	Herbert Joseph Spinden	Brooklyn, N. Y.
16	John Osborne Sumner	Boston
32	Charles Holt Taylor	Cambridge
11	Charles Cutler Torrey	New Haven, Conn.
11	Alfred Marston Tozzer	Cambridge
20	Clark Wissler	New York, N. Y.
34	Lawrence Counselman Wroth	Providence, R. I.

Class IV, Section III—*Philology*—59

31	Edward Cooke Armstrong	Princeton, N. J.
33	William Nickerson Bates	Philadelphia, Pa.
35	Charles Henry Beeson	Chicago, Ill.
33	Campbell Bonner	Ann Arbor, Mich.
35	Robert Johnson Bonner	Chicago, Ill.
33	Carleton Brown	New York, N. Y.
21	Carl Darling Buck	Chicago, Ill.
18	Edward Capps	Princeton, N. J.
20	Walter Eugene Clark	Cambridge

32	Ronald Salmon Crane	Chicago, Ill.
32	Morris William Croll	Princeton, N. J.
31	Samuel Hazzard Cross	Cambridge
20	Franklin Edgerton	New Haven, Conn.
21	Frank Edgar Farley	Middletown, Conn.
14	Jeremiah Denis Mathias Ford	Cambridge
35	Tenney Frank	Baltimore, Md.
30	James Geddes, Jr.	Brookline
13	Charles Hall Grandgent	Cambridge
16	Louis Herbert Gray	New York, N. Y.
25	William Chase Greene	Cambridge
13	Charles Burton Gulick	Cambridge
19	Roy Kenneth Hack	Cincinnati, Ohio
34	Austin Morris Harmon	New Haven, Conn.
31	Raymond Dexter Havens	Baltimore, Md.
18	George Lincoln Hendrickson	New Haven, Conn.
17	William Guild Howard	Cambridge
21	Eugene Xavier Louis Henry Hyvernat	Washington, D. C.
15	Carl Newell Jackson	Cambridge
13	James Richard Jewett	Cambridge
32	(Ralph) Hayward Keniston	Chicago, Ill.
34	Roland Grubb Kent	Philadelphia, Pa.
98	George Lyman Kittredge	Cambridge
33	Hans Kurath	Providence, R. I.
32	Ernest Felix Langley	Cambridge
[81] 98	Charles Rockwell Lanman	Cambridge
33	Ivan Mortimer Linforth	Berkeley, Cal.
31	Francis Peabody Magoun, Jr.	Cambridge
11	Albert Matthews	Boston
35	Benjamin Dean Meritt	Princeton, N. J.
28	William Albert Nitze	Chicago, Ill.
32	George Rapall Noyes	Berkeley, Cal.
34	William Abbott Oldfather	Urbana, Ill.
33	Howard Rollin Patch	Northampton
32	Arthur Stanley Pease	Cambridge
35	Henry Washington Prescott	Chicago, Ill.
13	Edward Kennard Rand	Cambridge
11	Fred Norris Robinson	Cambridge

31	Robert Kilburn Root	Princeton, N. J.
35	Henry Arthur Sanders	Ann Arbor, Mich.
18	Rudolph Schevill	Berkeley, Cal.
32	Horatio Elwin Smith	Providence, R. I.
04	Herbert Weir Smyth	Cambridge
89	Franklin Bache Stephenson	Washington, D. C.
32	William Thomson	Cambridge
33	George Benson Weston	Cambridge
28	Joshua Whatmough	Arlington
30	Ernest Hatch Wilkins	Oberlin, Ohio
33	Harry Austryn Wolfson	Cambridge
33	Karl Young	New Haven, Conn.

CLASS IV, SECTION IV—*The Fine Arts and Belles Lettres*—54

31	Stephen Vincent Benét	New York, N. Y.
26	Frank Weston Benson	Salem
32	(William) Welles Bosworth	New York, N. Y.
33	John Alden Carpenter	Chicago, Ill.
32	Chalmers Dancy Clifton	New York, N. Y.
33	Charles Collens	Newton Center
32	Kenneth John Conant	Cambridge
34	Charles Jay Connick	Newtonville
21	Frederick Shepherd Converse	Westwood
18	Charles Allerton Coolidge	Boston
29	Charles Townsend Copeland	Cambridge
[17] 30	Ralph Adams Cram	Boston
33	Cyrus Edwin Dallin	Arlington Heights
34	Samuel Foster Damon	Providence, R. I.
32	George Harold Edgell	Cambridge
21	William Emerson	Cambridge
33	Carl Engel	New York, N. Y.
30	John Erskine	New York, N. Y.
10	Arthur Fairbanks	Hanover, N. H.
18	Edward Waldo Forbes	Cambridge
31	Robert Frost	South Shaftsbury, Vt.
27	Wallace Goodrich	Boston
14	Robert Grant	Boston
17	Chester Noyes Greenough	Cambridge

29	Edward Burlingame Hill	Boston
31	Robert Silliman Hillyer	Cambridge
27	Charles Hopkinson	Manchester
12	Mark Antony DeWolfe Howe	Boston
18	Archer Milton Huntington	New York, N. Y.
31	Henry James	New York, N. Y.
(25) 32	William James	Cambridge
33	Leo Rich Lewis	Tufts College
20	John Ellerton Lodge	Washington, D. C.
21	John Livingston Lowes	Cambridge
21	Charles Donagh Maginnis	Brookline
31	Paul Manship	New York, N. Y.
31	Daniel Gregory Mason	New York, N. Y.
31	Frank Jewett Mather	Washington Crossing, Pa.
31	Kenneth Ballard Murdock	Cambridge
14	William Allan Neilson	Northampton
28	Curtis Hidden Page	Gilmanton, N. H.
21	William Lyon Phelps	New Haven, Conn.
(24) 32	Anthony John Philpott	Arlington
21	Chandler Rathfon Post	Cambridge
22	Paul Joseph Sachs	Cambridge
14	Ellery Sedgwick	Boston
19	Henry Dwight Sedgwick	Dedham
32	Henry Richardson Shepley	Brookline
33	David Stanley Smith	Woodbridge, Conn.
35	Walter Raymond Spalding	Cambridge
27	Edmund C. Tarbell	New Castle, N. H.
21	Charles Howard Walker	Boston
14	Owen Wister	Philadelphia, Pa.
22	Charles Henry Conrad Wright	Cambridge

FOREIGN HONORARY MEMBERS—121

(Number limited to one hundred and thirty)

CLASS I—*Mathematical and Physical Sciences*—34

SECTION I—*Mathematics and Astronomy*—9

22	Arthur Stanley Eddington	Cambridge, England
34	Ronald Aylmer Fisher	Harpenden, Herts
20	Jacques Salomon Hadamard	Paris
21	Godfrey Harold Hardy	Cambridge, England
27	Ejnar Hertzsprung	Leyden
17	Tullio Levi-Civita	Rome
03	Charles Emile Picard	Paris
15	Charles Jean de la Vallée Poussin	Louvain
29	Hermann Weyl	Princeton, N. J.

CLASS I, SECTION II—*Physics*—9

29	Vilhelm Frimann Koren Bjerknes	Oslo
24	Albert Einstein	Princeton, N. J.
29	James Franck	Baltimore, Md.
29	Abram F. Joffé	Leningrad
03	Sir Joseph Larmor	Cambridge, England
28	Friedrich Paschen	Charlottenburg
14	Max Planck	Berlin
15	Ernest Rutherford, Baron Rutherford	Cambridge, England
02	Sir Joseph John Thomson	Cambridge, England

CLASS I, SECTION III—*Chemistry*—8

29	Johannes N. Brönsted	Copenhagen
27	Peter Debye	Berlin
33	Jaroslav Heyrovsky	Prague
19	Henri Louis Le Chatelier	Paris
33	Fritz Paneth	London
28	Sören Peter Lauritz Sörensen	Copenhagen
29	Heinrich Wieland	Munich
34	Richard Willstätter	Munich

Class I, Section IV—*Technology and Engineering*—8

34	Paul Janet	Paris
34	Luigi Lombardi	Rome
25	Maurice d'Ocagne	Paris
29	Ludwig Prandtl	Göttingen
29	Emil Probst	Karlsruhe
29	Aurel Stodola	Zürich
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[15] 19	Charles Barrois	Lille
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29	Léon William Collet	Geneva
98	Albert Heim	Zürich
34	Arthur Holmes	Durham
22	Emmanuel de Margerie	Paris
21	Gustaf Adolf Frederik Molengraaff	Delft
18	Sir William Napier Shaw	London

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31	Ludwig Diels	Berlin
32	Kingo Miyabe	Sapporo, Japan
28	Alfred Barton Rendle	Leatherhead, Surrey, England
29	Otto Renner	Jena
32	Albert Charles Seward	Cambridge, England
35	Sir William Wright Smith	Edinburgh

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23	George Albert Boulenger	Brussels
20	Maurice Caullery	Paris
34	Archibald Vivian Hill	London
31	August Krogh	Copenhagen
30	Louis Édouard Lapicque	Paris

19	George Henry Falkiner Nuttall	Cambridge, England
28	Charles Tate Regan	London
33	Hans Spemann	Freiburg i. Br.
28	D'Arcy Wentworth Thompson	St. Andrews

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27	Sir Henry Hallett Dale	London
33	Sir Arthur Keith	London
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95	Rt. Hon. Sir Frederick Pollock, Bart	London
27	Joseph Redlich	Vienna
33	Rudolph Stammler	Wernigerode a. H.
33	Giorgio Del Vecchio	Rome

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28	Arthur Cecil Pigou	Cambridge, England
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33	Werner Sombart	Berlin
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30	Sir Aurel Stein	Srinagar, Kashmir
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31	Edgar Allison Peers	Liverpool
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Locke, E. A. F, II: 4
Lodge, J. E. F, IV: 4
Lombardi, L. FHM, I: 4
Longcope, W. T. F, II: 4
Loomis, F. B. F, II: 1
Lowell, A. L. F, III: 2
Lowes, J. L. F, IV: 4
Lull, R. S. F, II: 3
Lund, F. B. F, II: 4
Luyten, W. J. F, I: 1
Lyman, T. F, I: 2
McAdie, A. G. F, II: 1
McCollester, L. S. F, IV: 1
MacDonald, W. F, III: 2
McDougall, W. F, IV: 1
McEwen, G. F. F, II: 1
McIlwain, C. H. F, IV: 2
MacInnes, D. A. F, I: 3
MacIver, R. M. F, III: 3
McKeehan, L. W. F, I: 2
McLaren, W. W. F, III: 3
McLaughlin, D. H. F, II: 1
Macneil, S. F, III: 1
Maginnis, C. D. F, IV: 4
Magoun, F. P., Jr. F, IV: 3
Magrath, G. B. F, II: 4
Magruder, C. F, III: 1
Main, C. T. F, I: 4
Makarewicz, J. FHM, III: 1
Mallory, F. B. F, II: 4
Manship, P. F, IV: 4
Margerie, E. de. FHM, II: 1
Mark, E. L. F, II: 3
Mark, K. L. F, I: 3
Marks, L. S. F, I: 4
Marshall, L. C. F, III: 3
Mason, D. G. F, IV: 4
Mason, E. S. F, III: 3
Mather, F. J. F, IV: 4
Mather, K. F. F, II: 1
Mathews, E. B. F, II: 1
Matthews, A. F, IV: 3
Maunier, R. FHM, III: 3
May, J. V. F, III: 4
Mayo, W. J. F, II: 4
Mazon, P. FHM, IV: 3
Mead, A. D. F, II: 3
Mead, W. J. F, II: 1
Meillet, A. FHM, IV: 3
Meinecke, F. FHM, IV: 2
Melander, A. L. F, II: 3
Menzel, D. H. F, I: 1
Meriam, R. S. F, III: 3
Meritt, B. D. F, IV: 3

Merriam, C. E. F, III: 2
Merriam, J. C. F, II: 1
Merrill, E. D. F, II: 2
Merriman, R. B. F, IV: 2
Merritt, E. G. F, I: 2
Meyer, K. F. F, II: 3
Milas, N. A. F, I: 3
Miller, D. C. F, I: 2
Miller, G. A. F, I: 1
Miller, G. S. F, II: 3
Miller, J. A. F, I: 1
Miller, W. J. F, II: 1
Millikan, R. A. F, I: 2
Millis, H. A. F, III: 3
Mills, F. C. F, III: 3
Mills, O. L. F, III: 2
Mimno, H. R. F, I: 2
Miner, L. M. S. F, II: 4
Minot, G. R. F, II: 4
Mitchell, S. A. F, I: 1
Mitchell, W. C. F, III: 3
Mitchell, W. DeW. F, III: 1
Miyabe, K. FHM, II: 2
Miyajima, M. FHM, II: 4
Molengraaff, G. A. F. FHM, II: 1
Monroe, A. E. F, III: 3
Moore, E. C. F, IV: 1
Moore, J. B. F, III: 2
More, P. E. F, IV: 1
Moreland, E. L. F, I: 4
Morgan, E. M. F, III: 1
Morgan, T. H. F, II: 3
Morison, S. E. F, IV: 2
Morley, F. F, I: 1
Morris, F. K. F, II: 1
Morse, H. W. F, I: 2
Morse, M. F, I: 1
Morse, P. M. F, I: 2
Moss, W. L. F, II: 4
Moulton, F. R. F, I: 1
Moulton, H. G. F, III: 3
Mueller, E. F, I: 3
Müller, F. von. FHM, II: 4
Mueller, J. H. F, II: 4
Munro, W. B. F, III: 2
Munroe, C. E. F, I: 3
Murdock, K. B. F, IV: 4
Murray, G. FHM, IV: 4
Murray, H. A., Jr. F, IV: 1
Neal, H. V. F, II: 3
Neilson, W. A. F, IV: 4
Newhouse, W. H. F, II: 1
Nichols, E. L. F, I: 2
Nitze, W. A. F, IV: 3
Nock, A. D. F, IV: 1
Norris, J. F. F, I: 3
Norton, A. E. F, I: 4
Norton, C. L. F, I: 2
Nourse, E. G. F, III: 3
Noyes, A. A. F, I: 3
Noyes, G. R. F, IV: 3
Noyes, W. A. F, I: 3
Noyes, W. A., Jr. F, I: 3
Nuttall, G. H. F. FHM, II: 3
d'Ocagne, M. FHM, I: 4
O'Connell, W. H. F, IV: 1
O'Connor, J. F, IV: 1
Oertel, H. FHM, IV: 3
Ogburn, W. F. F, III: 3
Oldenberg, O. F, I: 2
Oldfather, W. A. F, IV: 3
Olmsted, F. L. F, I: 4
Osgood, R. B. F, II: 4
Osterhout, W. J. V. F, II: 2
Page, C. H. F, IV: 4
Page, L. F, I: 2
Palache, C. F, II: 1
Paneth, F. FHM, I: 3
Park, C. E. F, IV: 1
Park, C. F. F, I: 4
Park, R. E. F, III: 3
Parker, G. H. F, II: 3
Parker, H. F, III: 1
Parks, L. F, IV: 1
Paschen, F. FHM, I: 2
Patch, H. R. F, IV: 3
Peabody, F. G. F, IV: 1
Pearl, R. F, II: 3
Pearse, L. F, I: 4
Pearson, K. FHM, IV: 2
Pease, A. S. F, IV: 3
Peers, E. A. FHM, IV: 4

Peirce, G. J. F, II: 2
Pender, H. F, I: 4
Pepper, G. W. F, III: 1
Perkins, T. N. F, III: 4
Persons, W. M. F, III: 3
Peters, A. J. F, III: 4
Pfeiffer, R. H. F, IV: 2
Phelps, W. L. F, IV: 4
Phillips, H. B. F, I: 1
Phillips, J. C. F, II: 3
Philpott, A. J. F, IV: 4
Picard, C. E. FHM, I: 1
Pickard, G. W. F, I: 4
Pickering, W. H. F, I: 1
Pidal, R. M. FHM, IV: 3
Pierce, G. W. F, I: 2
Pigou, A. C. FHM, III: 3
Pilsbry, H. A. F, II: 3
Pirenne, H. FHM, IV: 2
Planck, M. FHM, I: 2
Pollock, Sir F. FHM, III: 1
Poor, C. L. F, I: 1
Post, C. R. F, IV: 4
Pound, R. F, III: 1
Prandtl, L. FHM, I: 4
Pratt, C. C. F, IV: 1
Pratt, F. H. F, II: 3
Pratt, J. H. F, II: 4
Prescott, H. W. F, IV: 3
Prescott, S. C. F, I: 3
Probst, E. FHM, I: 4
Putnam, H. F, III: 4
Putnam, T. J. F, II: 4
Quinby, W. C. F, II: 4
Rabaud, H. FHM, IV: 4
Rand, E. K. F, IV: 3
Rand, H. W. F, II: 3
Rapport, D. F, II: 3
Raymond, P. E. F, II: 1
Redfield, A. C. F, II: 3
Redlich, J. FHM, III: 1
Regan, C. T. FHM, II: 3
Rehder, A. F, II: 2
Reisner, G. A. F, IV: 2
Rendle, A. B. FHM, II: 2
Renner, O. FHM, II: 2
Richards, A. N. F, II: 3
Richards, R. H. F, I: 3
Richardson, R. G. D. F, I: 1
Richtmyer, F. K. F, I: 2
Riddle, O. F, II: 3
Ripley, A. L. F, III: 4
Rist, C. FHM, III: 3
Ritter, W. E. F, II: 3
Robinson, D. M. F, IV: 2
Robinson, F. N. F, IV: 3
Rogers, A. F. F, II: 1
Root, E. F, III: 1
Root, R. K. F, IV: 3
Rosanoff, M. A. F, I: 3
Rossby, C. G. A. F, II: 1
Rostovtzeff, M. I. F, IV: 2
Rowe, L. S. F, III: 3
Rugg, A. P. F, III: 1
Ruggles, A. H. F, II: 4
Russell, G. E. F, I: 4
Russell, H. N. F, I: 1
Rutherford, Baron FHM, I: 2
Ruthven, A. G. F, II: 3
Rutledge, G. F, I: 1
Ryan, J. H. F, IV: 1
Sachs, P. J. F, IV: 4
Sanders, H. A. F, IV: 3
Sapir, E. F, IV: 2
Sarton, G. F, IV: 2
Saunders, F. A. F, I: 2
Sauveur, A. F, I: 4
Sax, K. F, II: 2
Sayles, R. W. F, II: 1
Sayre, F. B. F, III: 1
Scatchard, G. F, I: 3
Schaller, W. T. F, II: 1
Schell, E. H. F, III: 4
Schevill, R. F, IV: 3
Schlesinger, F. F, I: 1
Schuchert, C. F, II: 1
Schumb, W. C. F, I: 3
Schumpeter, J. A. F, III: 3
Scott, A. W. F, III: 1
Scott, J. B. F, III: 1
Scott, W. B. F, II: 1
Sedgwick, E. F, IV: 4

Sedgwick, H. D. F, IV: 4
Sellards, A. W. F, II: 4
Setchell, W. A. F, II: 2
Seward, A. C. FHM, II: 2
Shapley, H. F, I: 1
Shattuck, G. C. F, II: 4
Shattuck, H. L. F, III: 4
Shaw, Sir W. N. FHM, II: 1
Shear, T. L. F, IV: 2
Shepley, H. R. F, IV: 4
Sherrill, H. K. F, IV: 1
Sherrill, M. S. F, I: 3
Sherrington, Sir C. S. FHM, II: 4
Shimer, H. W. F, II: 1
Sinnott, E. W. F, II: 2
Slater, J. C. F, I: 2
Slipher, V. M. F, I: 1
Slocum, F. F, I: 1
Smith, D. S. F, IV: 4
Smith, G. M. F, II: 2
Smith, H. E. F, IV: 3
Smith, H. M. F, I: 3
Smith, L. B. F, I: 3
Smith, P. F, III: 4
Smith, Sir W. W. FHM, II: 2
Smyth, H. L. F, I: 4
Smyth, H. W. F, IV: 3
Snyder, C. F, III: 3
Snyder, V. F, I: 1
Sörensen, S. P. L. FHM, I: 3
Sollmann, T. H. F, II: 4
Sombart, W. FHM, III: 3
Sorokin, P. A. F, III: 3
Spalding, W. R. F, IV: 4
Spemann, H. FHM, II: 3
Sperry, W. L. F, IV: 1
Spinden, H. J. F, IV: 2
Spofford, C. M. F, I: 4
Sprague, O. M. W. F, III: 3
Stafford, R. H. F, IV: 1
Stakman, E. C. F, II: 2
Stammler, R. FHM, II: 1
Stamp, Sir J. FHM, III: 4
Stearns, A. W. F, III: 4
Stebbins, J. F, I: 1
Stein, Sir A. FHM, IV: 2
Steinmetz, S. R. FHM, III: 3
Stephenson, F. B. F, IV: 3
Stetson, H. T. F, I: 1
Stevens, J. F. F, I: 4
Stieglitz, J. O. F, I: 3
Stiles, C. W. F, II: 4
Stiles, P. G. F, II: 3
Stodola, A. FHM, I: 4
Stone, H. F. F, III: 1
Stone, J. S. F, I: 2
Stone, M. H. F, I: 1
Strong, R. P. F, II: 4
Struik, D. J. F, I: 1
Struve, P. B. FHM, III: 3
Sumner, J. O. F, IV: 2
Talbot, F. B. F, II: 4
Tamarkin, J. D. F, I: 1
Tarbell, E. C. F, IV: 4
Taussig, F. W. F, III: 3
Taylor, C. H. F, III: 4
Taylor, C. H. F, IV: 2
Taylor, F. B. F, II: 1
Teggart, F. J. F, III: 3
Terman, L. M. F, IV: 1
Terry, C. S. FHM, IV: 2
Theiler, Sir A. FHM, II: 4
Thomas, F. W. FHM, IV: 3
Thomas, W. I. F, III: 3
Thompson, D'A. W. FHM, II: 3
Thompson, M. deK. F, I: 2
Thomson, E. F, I: 2
Thomson, Sir J. J. FHM, I: 2
Thomson, W. F, IV: 3
Thorndike, E. L. F, IV: 1
Thurston, E. S. F, III: 1
Thwing, C. F. F, III: 4
Timonoff, V. E. FHM, I: 4
Tolman, R. C. F, I: 3
Torrey, C. C. F, IV: 2
Tozzer, A. M. F, IV: 2
Trelease, W. F, II: 2
Trevelyan, G. M. FHM, IV: 2
Tucker, D. S. F, III: 3
Tyler, H. W. F, I: 1
Tyzzer, E. E. F, II: 4
Usher, A. P. F, III: 3

Vallarta, M. S. F, I: 2
Vallée Poussin, C. J. de la. FHM, I: 1
Van de Graaff, R. J. F, I: 2
Van Vleck, J. H. F, I: 2
Vaughan, T. W. F, II: 1
Veblen, O. F, I: 1
Vecchio, G. Del. FHM, III: 1
Verhoeff, F. H. F, II: 4
Viner, J. F, III: 3
Wagner, K. W. FHM, I: 4
Walker, C. H. F, IV: 4
Walsh, J. L. F, I: 1
Wambaugh, E. F, III: 1
Warner, E. P. F, I: 4
Warren, B. E. F, I: 2
Warren, C. H. F, II: 1
Washburn, H. B. F, IV: 1
Watson, J. B. F, IV: 1
Wearn, J. T. F, II: 4
Weatherby, C. A. F, II: 2
Webster, D. L. F, I: 2
Webster, E. S. F, III: 4
Weiss, S. F, II: 4
Wells, A. E. F, I: 4
Wells, F. L. F, IV: 1
Weston, G. B. F, IV: 3
Weston, R. S. F, I: 4
Weston, W. H. F, II: 2
Wetmore, R. H. F, II: 2
Weyl, H. FHM, I: 1
Weysse, A. W. F, II: 3
Whatmough, J. F, IV: 3
Wheeler, W. M. F, II: 3
White, B. F, II: 4
Whitehead, A. N. F, I: 1
Whitlock, H. P. F, II: 1
Whitman, E. A. F, III: 1
Whitney, W. R. F, I: 3
Whittlesey, D. S. F, II: 1
Widder, D. V. F, I: 1
Wieland, H. FHM, I: 3
Wilkins, E. H. F, IV: 3
Williams, F. H. F, II: 4
Williams, J. H. F, III: 3
Williams, R. S. F, I: 3
Willis, B. F, II: 1
Willoughby, W. F. F, III: 2
Willoughby, W. W. F, III: 2
Willstätter, R. FHM, I: 3
Wilson, E. B. F, II: 3
Wilson, E. B. F, I: 2
Wilson, G. G. F, III: 2
Winsor, F. E. F, I: 4
Wissler, C. F, IV: 2
Wister, O. F, IV: 4
Wolbach, S. B. F, II: 4
Wolff, J. E. F, II: 1
Wolfson, H. A. F, IV: 3
Wolman, L. F, III: 3
Wood, R. W. F, I: 2
Woodman, A. G. F, I: 3
Woods, F. A. F, II: 3
Woods, F. S. F, I: 1
Woodworth, R. S. F, IV: 1
Worcester, J. R. F, I: 4
Worrall, D. E. F, I: 3
Wright, C. H. C. F, IV: 4
Wright, F. E. F, II: 1
Wright, Q. F, III: 2
Wroth, L. C. F, IV: 2
Wyman, J., Jr. F, II: 3
Yeomans, H. A. F, III: 2
Yerkes, R. M. F, IV: 1
Young, B. L. F, III: 4
Young, K. F, IV: 3
Zeleny, J. F, I: 2
Zimmerman, C. C. F, III: 3
Zinsser, H. F, II: 4

STATUTES AND STANDING VOTES.

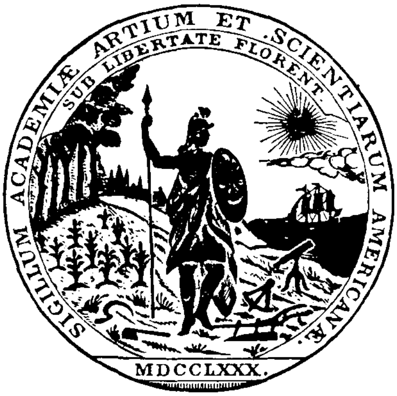
STATUTES.

Adopted November 8, 1911: *amended May* 8, 1912, *January* 8, *and May* 14, 1913, *April* 14, 1915, *April* 12, 1916, *April* 10, 1918, *May* 14, 1919, *February* 8, *April* 12, *and December* 13, 1922, *February* 14, *March* 14, *and October* 10, 1923, *March* 10, 1926, *May* 9, 1928, *April* 8 *and November* 11, 1931, *April* 12, 1933, *and February* 14, 1934.

CHAPTER I.

THE CORPORATE SEAL.

ARTICLE 1. The Corporate Seal of the Academy shall be as here depicted:


SIGILLUM ACADEMIÆ ARTIUM ET SCIENTIARUM AMERICANÆ.
SUB LIBERTATE FLORENT
MDCCLXXX.

ARTICLE 2. The Recording Secretary shall have the custody of the Corporate Seal.

See Chap. v, art. 3; chap. vi, art. 2.

CHAPTER II.

Fellows and Foreign Honorary Members and Dues.

Article 1. The Academy consists of Fellows, who are either citizens or residents of the United States of America, and Foreign Honorary Members. They are arranged in four Classes, according to the Arts and Sciences in which they are severally proficient, and each Class is divided into four Sections, namely:

Class I. *The Mathematical and Physical Sciences*

Section 1.	Mathematics and Astronomy
Section 2.	Physics
Section 3.	Chemistry
Section 4.	Technology and Engineering

Class II. *The Natural and Physiological Sciences*

Section 1.	Geology, Mineralogy, and Physics of the Globe
Section 2.	Botany
Section 3.	Zoölogy and Physiology
Section 4.	Medicine and Surgery

Class III. *The Social Arts*

Section 1.	Jurisprudence
Section 2.	Government, International Law, and Diplomacy
Section 3.	Economics and Sociology
Section 4.	Administration and Affairs

Class IV. *The Humanities*

Section 1.	Theology, Philosophy, and Psychology
Section 2.	History, Archæology, and Anthropology
Section 3.	Philology
Section 4.	The Fine Arts and Belles Lettres

Article 2. The number of Fellows shall not exceed Eight hundred, of whom not more than Six hundred shall be residents of Massachusetts, nor shall there be more than Two hundred and twenty in any one Class.

Article 3. The number of Foreign Honorary Members shall not exceed One hundred and thirty. They shall be chosen from among citizens of foreign countries most eminent for their discoveries and attainments in any of the Classes above enumerated. There shall not be more than Thirty-five in any one Class.

ARTICLE 4. If any person, after being notified of his election as Fellow, shall neglect for six months to accept in writing, or, if a Fellow resident within fifty miles of Boston shall neglect to pay his Admission Fee, his election shall be void; and if any Fellow resident within fifty miles of Boston shall neglect to pay his Annual Dues for six months after they are due, provided his attention shall have been called to this Article of the Statutes in the meantime, he shall cease to be a Fellow; but the Council may suspend the provisions of this Article for a reasonable time.

With the previous consent of the Council, the Treasurer may dispense (*sub silentio*) with the payment of the Admission Fee or of the Annual Dues or both whenever he shall deem it advisable. In the case of officers of the Army or Navy who are out of the Commonwealth on duty, payment of the Annual Dues may be waived during such absence if continued during the whole financial year and if notification of such expected absence be sent to the Treasurer. Upon similar notification to the Treasurer, similar exemption may be accorded to Fellows subject to Annual Dues, who may temporarily remove their residence for at least two years to a place more than fifty miles from Boston.

If any person elected a Foreign Honorary Member shall neglect for six months after being notified of his election to accept in writing, his election shall be void.

See Chap. vii, art. 2.

ARTICLE 5. Every Fellow resident within fifty miles of Boston hereafter elected shall pay an Admission Fee of Ten dollars, unless previously as an Associate he has paid an Admission Fee of like amount.

Every Fellow resident within fifty miles of Boston shall, and others may, pay such Annual Dues, not exceeding Fifteen dollars, as shall be voted by the Academy at each Annual Meeting, when they shall become due; but any Fellow shall be exempt from the annual payment if, at any time after his admission, he shall pay into the treasury Two hundred dollars in addition to his previous payments. Any Fellow shall also be exempt from Annual Dues who has paid such dues for forty years, or, having attained the age of seventy-five has paid dues for twenty-five years.

All Commutations of the Annual Dues shall be and remain permanently founded, the interest only to be used for current expenses.

Any Fellow not previously subject to Annual Dues who takes up his residence within fifty miles of Boston, shall pay to the Treasurer within three months thereafter Annual Dues for the current year, failing which his Fellowship shall cease; but the Council may suspend the provisions of this Article for a reasonable time.

Only Fellows who pay Annual Dues or have commuted them may hold office in the Academy or serve on the Standing Committees or vote at meetings.

ARTICLE 6. Fellows who pay or have commuted the Annual Dues and Foreign Honorary Members shall be entitled to receive gratis one copy of all Publications of the Academy issued after their election.

See Chap. xi, art. 2.

ARTICLE 7. Diplomas signed by the President and the Vice-President of the Class to which the member belongs, and countersigned by the Secretaries, shall be given to Foreign Honorary Members and to Fellows on request.

ARTICLE 8. If, in the opinion of a majority of the entire Council, any Fellow or Foreign Honorary Member shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his membership; and if three-fourths of the Fellows present, out of a total attendance of not less than fifty at a Stated Meeting, or at a Special Meeting called for the purpose, shall adopt this recommendation, his name shall be stricken from the Roll.

See Chap. iii; chap. vi, art. 1; chap. x, art. 1, 7; chap. xi, art. 2.

CHAPTER III.

ELECTION OF FELLOWS AND FOREIGN HONORARY MEMBERS.

The procedure in the election of Fellows and Foreign Honorary Members shall be as follows:

Nominations to Fellowship or Foreign Honorary Membership in any Section must be signed by Two Fellows of that Section, or by three Fellows of any Sections, and sent to the Corresponding Secretary accompanied by a statement of the qualifications of the nominee and brief biographical data.

Notice shall be sent to every Fellow not later than the fifteenth of January in each year, reminding him that all nominations must be in the hands of the Corresponding Secretary before the fifteenth of February following.

A list of the nominees, giving a brief account of each, with the names of the nominators, shall be sent to every Fellow with a request that he return the list with such confidential comments and indications of preference as he may choose to make.

All the nominations, with any comments thereon and with expressions of preference on the part of the Fellows, shall be referred to the appropriate Class Committees, which shall canvass them, and report their recommendations in writing to the Council before the Stated Meeting of the Academy in April.

Elections of Fellows and Foreign Honorary Members shall be made by the Council before the Annual Meeting in May, and announced at that meeting.

Persons nominated in any year, but not elected, may be carried over to the list of nominees for the next year at the discretion of the Council, but shall not be further continued unless renominated.

See Chap. ii; chap. vi, art. 1; chap. x, art. 1.

CHAPTER IV.

OFFICERS.

ARTICLE 1. The Officers of the Academy shall be a President (who shall be Chairman of the Council), four Vice-Presidents (one from each Class), a Corresponding Secretary (who shall be Secretary of the Council), a Recording Secretary, a Treasurer, a Librarian, and an Editor, all of whom shall be elected by ballot at the Annual Meeting, and shall hold their respective offices for one year, and until others are duly chosen and installed.

There shall be also sixteen Councillors, one from each Section of each Class. At each Annual Meeting four Councillors, one from each Class, shall be elected by ballot to serve for the full term of four years and until others are duly chosen and installed. The same Fellow shall not be eligible for two successive terms.

The Councillors, with the other officers previously named, and the Chairman of the House Committee, *ex officio*, shall constitute the Council.

See Chap. xi, art. 1.

ARTICLE 2. If any officer be unable, through death, absence, or disability, to fulfill the duties of his office, or if he shall resign, his place may be filled by the Council in its discretion for any part or the whole of the unexpired term.

ARTICLE 3. At the Stated Meeting in March, the President shall appoint a Nominating Committee of four Fellows having the right to vote, one from each Class. This Committee shall prepare a list of nominees for the several offices to be filled, and for the Standing Committees, and file it with the Recording Secretary not later than four weeks before the Annual Meeting.

See Chap. vi, art. 2.

ARTICLE 4. Independent nominations for any office, if signed by at least twenty Fellows having the right to vote, and received by the Recording Secretary not less than ten days before the Annual Meeting, shall be inserted in the call therefor, and shall be mailed to all the Fellows having the right to vote.

See Chap. vi, art. 2.

ARTICLE 5. The Recording Secretary shall prepare for use in voting at the Annual Meeting a ballot containing the names of all persons duly nominated for office.

CHAPTER V.

THE PRESIDENT.

ARTICLE 1. The President, or in his absence the senior Vice-President present (seniority to be determined by length of continuous Fellowship in the Academy), shall preside at all meetings of the Academy. In the absence of all these officers, a Chairman of the meeting shall be chosen by ballot.

ARTICLE 2. Unless otherwise ordered, all Committees which are not elected by ballot shall be appointed by the presiding officer.

ARTICLE 3. Any deed or writing to which the Corporate Seal is to be affixed, except leases of real estate, shall be executed in the name of the Academy by the President or, in the event of his death, absence, or inability, by one of the Vice-Presidents, when thereto duly authorized.

See Chap. ii, art. 7; chap. iv, art. 1, 3; chap. vi, art. 2; chap. vii, art. 1; chap. x, art. 6; chap. xi, art. 1, 2; chap. xii, art. 1.

CHAPTER VI.

THE SECRETARIES.

ARTICLE 1. The Corresponding Secretary shall conduct the correspondence of the Academy and of the Council, recording or making an entry of all letters written in its name, and preserving for the files all official papers which may be received. At each meeting of the Council he shall present the communications addressed to the Academy which have been received since the previous meeting, and at the next meeting of the Academy he shall present such as the Council may determine.

He shall notify all persons who may be elected Fellows or Foreign Honorary Members, send to each a copy of the Statutes, and on their acceptance issue the proper Diploma. He shall also notify all meetings of the Council; and in case of the death, absence, or inability of the Recording Secretary he shall notify all meetings of the Academy.

Under the direction of the Council, he shall keep a List of the Fellows and Foreign Honorary Members, arranged in their several Classes and Sections. It shall be printed annually and issued as of the first day of July.

See Chap. ii, art. 7; chap. iii; chap. iv, art. 1; chap. x, art. 6; chap. xi art. 1; chap. xii, art. 1.

ARTICLE 2. The Recording Secretary shall have the custody of the Charter, Corporate Seal, Archives, Statute-Book, Journals, and all literary papers belonging to the Academy.

Fellows borrowing such papers or documents shall receipt for them to their custodian.

The Recording Secretary shall attend the meetings of the Academy and keep a faithful record of the proceedings with the names of the Fellows present; and after each meeting is duly opened, he shall read the record of the preceding meeting.

He shall notify the meetings of the Academy to each Fellow and by mail at least seven days beforehand, and in his discretion may also cause the meetings to be advertised; he shall apprise Officers and Committees of their election or appointment, and inform the Treasurer of appropriations of money voted by the Academy.

After all elections, he shall insert in the Records the names of the Fellows by whom the successful nominees were proposed.

He shall send the Report of the Nominating Committee in print to every Fellow having the right to vote at least three weeks before the Annual Meeting.

See Chap. iv, art. 3.

In the absence of the President and of the Vice-Presidents he shall, if present, call the meeting to order, and preside until a Chairman is chosen.

See Chap. i; chap. ii, art. 7; chap. iv, art. 3, 4, 5; chap. x, art. 6; chap. xi, art. 1, 2; chap. xii, art. 1, 3.

ARTICLE 3. The Secretaries, with the Editor, shall have authority to publish such of the records of the meetings of the Academy as may seem to them likely to promote its interests.

CHAPTER VII.

THE TREASURER AND THE TREASURY.

ARTICLE 1. The Treasurer shall collect all money due or payable to the Academy, and all gifts and bequests made to it. He shall pay all bills due by the Academy, when approved by the proper officers, except those of the Treasurer's office, which may be paid without such approval; in the name of the Academy he shall sign all leases of real estate; and, with the written consent of a member of the Committee on Finance, he shall make all transfers of stocks, bonds, and other securities belonging to the Academy, all of which shall be in his official custody.

He shall keep a faithful account of all receipts and expenditures, submit his accounts annually to the Auditing Committee, and render them at the expiration of his term of office, or whenever required to do so by the Academy or the Council.

He shall keep separate accounts of the income of the Rumford Fund, and of all other special Funds, and of the Appropriation thereof, and render them annually.

His accounts shall always be open to the inspection of the Council.

Article 2. He shall report annually to the Council at its March meeting on the expected income of the various Funds and from all other sources during the ensuing financial year. He shall also report the names of all Fellows who may be then delinquent in the payment of their Annual Dues.

Article 3. He shall give such security for the trust reposed in him as the Academy may require.

Article 4. With the approval of a majority of the Committee on Finance, he may appoint an Assistant Treasurer to perform his duties, for whose acts, as such assistant, he shall be responsible; or, with like approval and responsibility, he may employ any Trust Company doing business in Boston as his agent for the same purpose, the compensation of such Assistant Treasurer or agent to be fixed by the Committee on Finance and paid from the Funds of the Academy.

Article 5. At the Annual Meeting he shall report in print all his official doings for the preceding year, stating the amount and condition of all the property of the Academy entrusted to him, and the character of the investments.

Article 6. The Financial Year of the Academy shall begin with the first day of April.

Article 7. No person or committee shall incur any debt or liability in the name of the Academy, unless in accordance with a previous vote and appropriation therefor by the Academy or the Council, or sell or otherwise dispose of any property of the Academy, except cash or invested funds, without previous consent and approval of the Council.

See Chap. ii, art. 4, 5; chap. vi, art. 2; chap. x, art. 6; chap. xi, art. 1, 2, 3; chap. xii, art. 1.

CHAPTER VIII.

The Librarian and the Library.

Article 1. The Librarian shall have charge of the printed books, keep a correct catalogue thereof, and provide for their delivery from the Library.

At the Annual Meeting, as Chairman of the Committee on the Library, he shall make a Report on its condition.

Article 2. In conjunction with the Committee on the Library he shall have authority to expend such sums as may be appropriated by the Academy for the purchase of books, periodicals, etc., and for defraying other necessary expenses connected with the Library.

Article 3. All books procured from the income of the Rumford Fund or of other special Funds shall contain a book-plate expressing the fact.

Article 4. Books taken from the Library shall be receipted for to the Librarian or his assistant.

Article 5. Books shall be returned in good order, regard being had to necessary wear with good usage. If any book shall be lost or injured, the Fellow to whom it stands charged shall replace it by a new volume or by a new set, if it belongs to a set, or pay the current price thereof to the Librarian, whereupon the remainder of the set, if any, shall be delivered to the Fellow so paying, unless such remainder be valuable by reason of association.

Article 6. All books shall be returned to the Library for examination at least one week before the Annual Meeting.

Article 7. The Librarian shall have the custody of the Publications of the Academy. With the advice and consent of the President, he may effect exchanges with other associations.

See Chap. ii, art. 6; chap. xi, art. 1, 2.

CHAPTER IX.

The Editor and the Publications.

Article 1. The Editor shall have charge of the conduct through the press of the Proceedings and the Memoirs, and all correspondence relative thereto, and shall have power to fix the price at which individual numbers of the Proceedings and Memoirs are sold.

Article 2. In conjunction with the Committee of Publication, he shall have authority to expend such sums as may be appropriated by the Academy for printing the publications and for defraying other expenses therewith connected.

Article 3. All publications which are financed in whole or in part from the income of the Rumford Fund or from the income of other special funds, and all publications of work done with the aid of the Rumford Fund or other special funds, shall contain a conspicuous statement of this fact.

Article 4. Two hundred extra copies of each paper printed in the Proceedings or Memoirs shall be placed at the disposal of the author without charge.

If, on account of the number of communications offered for publication, it shall be necessary to decline for publication communications otherwise acceptable, members of the Academy shall be given preference in each of the several Classes over non-members; but whenever it shall be necessary to exercise this preference, the Editor shall inform the Council of the fact.

See Chap. iv, art. 1; chap. vi, art. 3; chap. x, art. 6; chap. xi, art. 4.

CHAPTER X.

The Council.

Article 1. The Council shall exercise a discreet supervision over all nominations and elections to membership, and in general supervise all the affairs of the Academy not explicitly reserved to the Academy as a whole or entrusted by it or by the Statutes to standing or special committees.

It shall consider all nominations duly sent to it by any Class Committee, and act upon them in accordance with the provisions of Chapter III.

With the consent of the Fellow interested, it shall have power to make transfers between the several Sections, reporting its action to the Academy.

See Chap. iii, art. 2, 3; chap. xi, art. 1.

Article 2. Nine members shall constitute a quorum.

Article 3. It shall establish rules and regulations for the transaction of its business, and provide all printed and engraved blanks and books of record.

Article 4. It shall act upon all resignations of officers, and all resignations and forfeitures of Fellowship; and cause the Statutes to be faithfully executed.

It shall appoint all agents and subordinates not otherwise provided for by the Statutes, prescribe their duties, and fix their compensation. They shall hold their respective positions during the pleasure of the Council.

ARTICLE 5. It may appoint, for terms not exceeding one year, and prescribe the functions of, such committees of its number, or of the Fellows of the Academy, as it may deem expedient, to facilitate the administration of the affairs of the Academy or to promote its interests.

ARTICLE 6. At its March meeting it shall receive reports from the President, the Secretaries, the Treasurer, and the Standing Committees, on the appropriations severally needed for the ensuing financial year. At the same meeting the Treasurer shall report on the expected income of the various Funds and from all other sources during the same year.

A report from the Council shall be submitted to the Academy, for action, at the March meeting, recommending the appropriation which in the opinion of the Council should be made.

On the recommendation of the Council, special appropriations may be made at any Stated Meeting of the Academy, or at a Special Meeting called for the purpose.

See Chap. xi, art. 3.

ARTICLE 7. After the death of a Fellow or Foreign Honorary Member, it shall appoint a member of the Academy to provide a biographical notice for publication in the Proceedings.

ARTICLE 8. It shall report at every meeting of the Academy such business as it may deem advisable to present.

See Chap. ii, art. 4, 5, 8; chap. iv, art. 1, 2; chap. vi, art. 1; chap. vii, art. 1; chap. xii, art. 1, 4.

CHAPTER XI.

STANDING COMMITTEES.

ARTICLE 1. The Class Committee of each Class shall consist of the Vice-President, who shall be chairman, and the four Councillors of the Class, together with such other officer or officers annually elected as may belong to the Class. It shall consider nominations to Fellowship in its own Class, and report in writing to the Council such as may receive at a Class Committee Meeting a majority of the votes cast, provided at least three shall have been in the affirmative.

See Chap. iii, art. 2.

ARTICLE 2. At the Annual Meeting the following Standing Committees shall be elected by ballot to serve for the ensuing year:

(i) *The Committee on Finance*, to consist of four Fellows, who, through the Treasurer, shall have full control and management of the funds and trusts of the Academy, with the power of investing the funds and changing the investments thereof in their discretion.

See Chap. iv, art. 3; chap. vii, art. 1, 4; chap. x, art. 6.

(ii) *The Rumford Committee*, to consist of seven Fellows, who shall report to the Academy on all applications and claims for the Rumford Premium. It alone shall authorize the purchase of books, publications and apparatus at the charge of the income from the Rumford Fund, and generally shall see to the proper execution of the trust.

See Chap. iv, art. 3; chap. x, art. 6.

(iii) *The Cyrus Moors Warren Committee*, to consist of seven Fellows, who shall consider all applications for appropriations from the income of the Cyrus Moors Warren Fund, and generally shall see to the proper execution of the trust.

See Chap. iv, art. 3; chap. x, art. 6.

(iv) *The Committee of Publication*, to consist of the Editor, *ex officio*, as Chairman, and four other Fellows, one from each Class, to whom all communications submitted to the Academy for publication shall be referred, and to whom the printing of the Proceedings and the Memoirs shall be entrusted.

It shall fix the price at which volumes of the publications shall be sold; but Fellows may be supplied at half price with volumes which they are not entitled to receive gratis.

It shall determine when the pressure of material offered for publication makes it necessary to give preference to members of the Academy as compared with non-members, or to give priority to certain members as compared with others, and to what extent this preference or priority shall be applied in each of the four Classes, to the end that a proper balance of the facilities of publication with respect to subject matter and authors may be maintained.

See Chap. iv, art. 3; chap. vi, art. 1, 3; chap. ix; chap. x, art. 6.

(v) *The Committee on the Library*, to consist of the Librarian, *ex officio*, as Chairman, and four other Fellows, one from each Class, who shall examine the Library and make an annual report on its condition and management.

See Chap. iv, art. 3; chap. viii, art. 1, 2; chap. x, art. 6.

(vi) *The House Committee*, to consist of four Fellows, who shall have charge of all expenses connected with the House, including the general expenses of the Academy not specifically assigned to the care of other Committees or Officers.

See Chap. iv, art. 1, 3; chap. x, art. 6.

(vii) *The Committee on Meetings*, to consist of the President, the Recording Secretary, and four other Fellows, who shall have charge of plans for meetings of the Academy.

See Chap. iv, art. 3; chap. x, art. 6.

(viii) *The Auditing Committee*, to consist of two Fellows, who shall audit the accounts of the Treasurer, with power to employ an expert and to approve his bill.

See Chap. iv, art. 3; chap. vii, art. 1; chap. x, art. 6.

(ix) *The Committee on Biographical Notices*, to consist of six Fellows, two to be elected each year, six in 1933, one of them to be a Secretary of the Academy, to see that biographical notices of the Fellows are provided.

See Chap. x, art. 7.

ARTICLE 3. The Standing Committees shall report annually to the Council in March on the appropriations severally needed for the ensuing financial year; and all bills incurred on account of these Committees, within the limits of the several appropriations made by the Academy, shall be approved by their respective Chairmen.

In the absence of the Chairman of any Committee, bills may be approved by any member of the Committee whom he shall designate for the purpose.

See Chap. vii, art. 1, 7; chap. x, art. 6.

CHAPTER XII.

MEETINGS, COMMUNICATIONS, AND AMENDMENTS.

ARTICLE 1. There shall be annually eight Stated Meetings of the Academy, namely, on the second Wednesday of October, November, December, January, February, March, April, and May. Only at these meetings, or at adjournments thereof regularly notified, or at Special Meetings called for the purpose, shall appropriations of money be made or amendments of the Statutes or Standing Votes be effected.

The Stated Meeting in May shall be the Annual Meeting of the Corporation.

Special Meetings shall be called by either of the Secretaries at the request of the President, of a Vice-President, of the Council, or of ten Fellows having the right to vote; and notifications thereof shall state the purpose for which the meeting is called.

A meeting for receiving and discussing literary or scientific communications may be held on the fourth Wednesday of each month, excepting July, August, and September; but no business shall be transacted at said meetings.

ARTICLE 2. Twenty-five Fellows having the right to vote shall constitute a quorum for the transaction of business at Stated or Special Meetings. Eighteen Fellows shall be sufficient to constitute a meeting for literary or scientific communications and discussions.

ARTICLE 3. Upon the request of the presiding officer or the Recording Secretary, any motion or resolution offered at any meeting shall be submitted in writing.

ARTICLE 4. No report of any paper presented at a meeting of the Academy shall be published by any Fellow without the consent of the author; and no report shall in any case be published by any Fellow in a newspaper as an account of the proceedings of the Academy without the previous consent and approval of the Council. The Council, in its discretion, by a duly recorded vote, may delegate its authority in this regard to one or more of its members.

ARTICLE 5. No Fellow shall introduce a guest at any meeting of the Academy until after the business has been transacted, and especially until after the result of the balloting upon nominations has been declared.

ARTICLE 6. The Academy shall not express its judgement on literary or scientific memoirs or performances submitted to it, or included in its Publications.

ARTICLE 7. All proposed Amendments of the Statutes shall be referred to a committee, and on its report, at a subsequent Stated Meeting or at a Special Meeting called for the purpose, two-thirds of the ballot cast, and not less than twenty-five, must be affirmative to effect enactment.

ARTICLE 8. Standing Votes may be passed, amended, or rescinded at a Stated Meeting, or at a Special Meeting called for the purpose, by a vote of two-thirds of the members present. They may be suspended by a unanimous vote.

See Chap. ii, art. 5, 8; chap. iii; chap. iv, art. 3, 4, 5; chap. v, art. 1; chap. vi, art. 1, 2; chap. x, art. 8.

STANDING VOTES.

1. Communications of which notice has been given to either of the Secretaries shall take precedence of those not so notified.

2. Fellows may take from the Library six volumes at any one time, and may retain them for three months, and no longer. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library for a limited period.

3. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy without the leave of the Librarian.

4. The Council, under such rules respecting nominations as it may prescribe, may elect as Associates of the Academy a limited number of men of mark in affairs or of distinguished service in the community.

Associates shall be entitled to the same privileges as Fellows, but shall not have the right to vote.

The admission fee and annual dues of Associates shall be the same as those of Fellows residing within fifty miles of Boston.

5. Communications offered for publication in the Proceedings or Memoirs of the Academy shall not be accepted for publication before the author shall have informed the Committee on Meetings of his readiness, either himself or through some agent, to use such time as the Committee may assign him at such meeting as may be convenient both to him and to the Committee, for the purpose of presenting to the Academy a general statement of the nature and significance of the results contained in his communication.

RUMFORD PREMIUM.

In conformity with the terms of the gift of Sir Benjamin Thompson, Count Rumford, of a certain Fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court of Massachusetts for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of the Rumford Fund, as it now exists, at any Annual Meeting, an award of a gold and a silver medal, being together of the intrinsic value of three hundred dollars, as a Premium to the author of any important discovery or useful improvement in light or heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands; preference always being given to such discoveries as, in the opinion of the Academy, shall tend most to promote the good of mankind; and, if the Academy sees fit, to add to such medals, as a further Premium for such discovery and improvement, a sum of money not exceeding three hundred dollars.

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OF THE

AMERICAN ACADEMY

OF

ARTS AND SCIENCES

VOL. LXX

FROM MAY 1934, TO MAY 1935

MDCCLXXX.

BOSTON:
PUBLISHED BY THE ACADEMY
1936

Intelligencer Printing Co.
Lancaster, Pa.

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